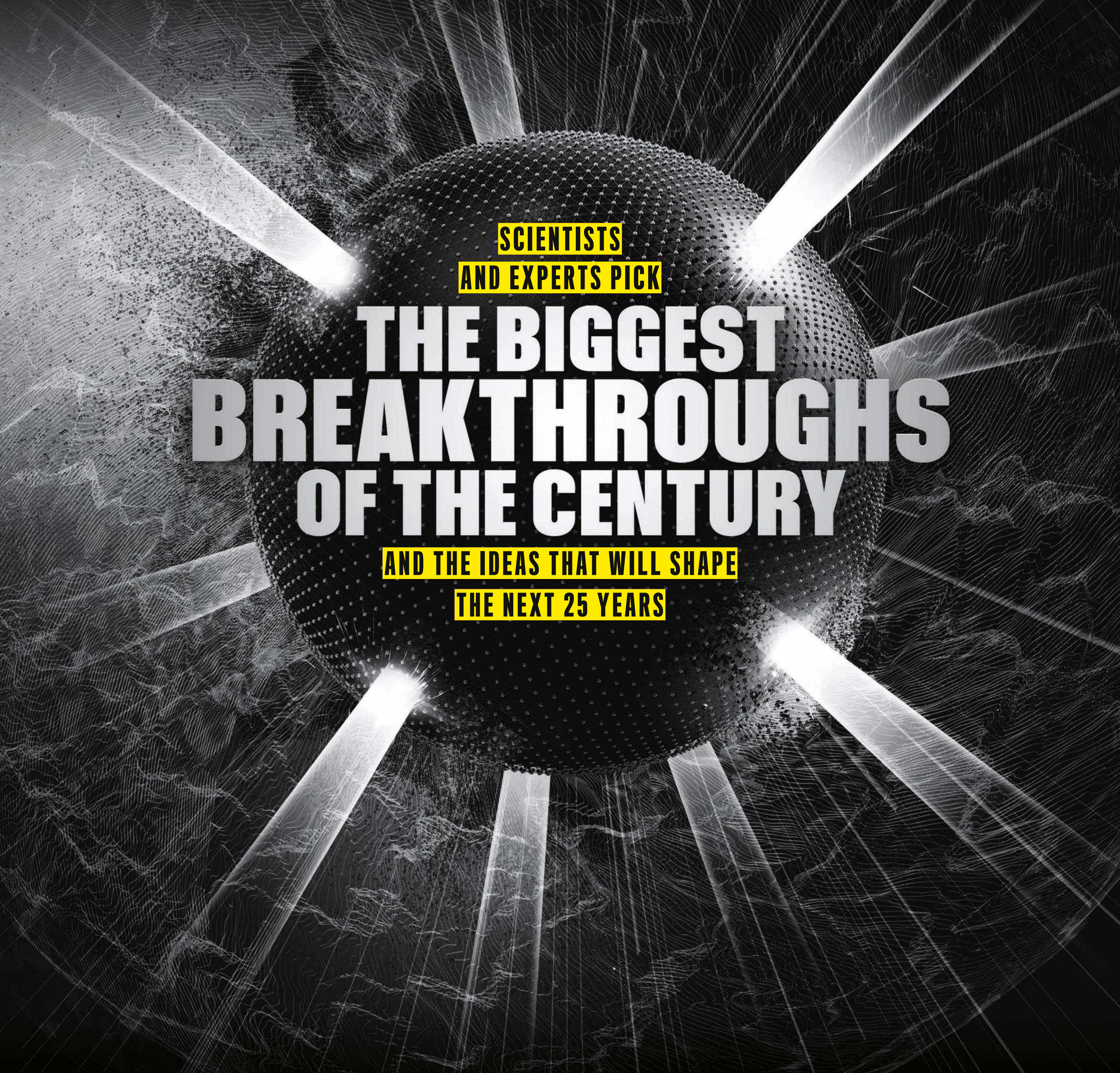
HOW TO CHANGE YOUR PERSONALITY

Science Focus

Inside the
PENTAGON'S UFO FILES

How human activity is
CHANGING EARTH'S SPIN

Which makeup is
HARMING YOUR HEALTH?



SCIENTISTS
AND EXPERTS PICK

THE BIGGEST BREAKTHROUGHS OF THE CENTURY

AND THE IDEAS THAT WILL SHAPE
THE NEXT 25 YEARS

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Tech
The terrible ideas we wish
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How 'cognitive shuffling'
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Can you overcome your
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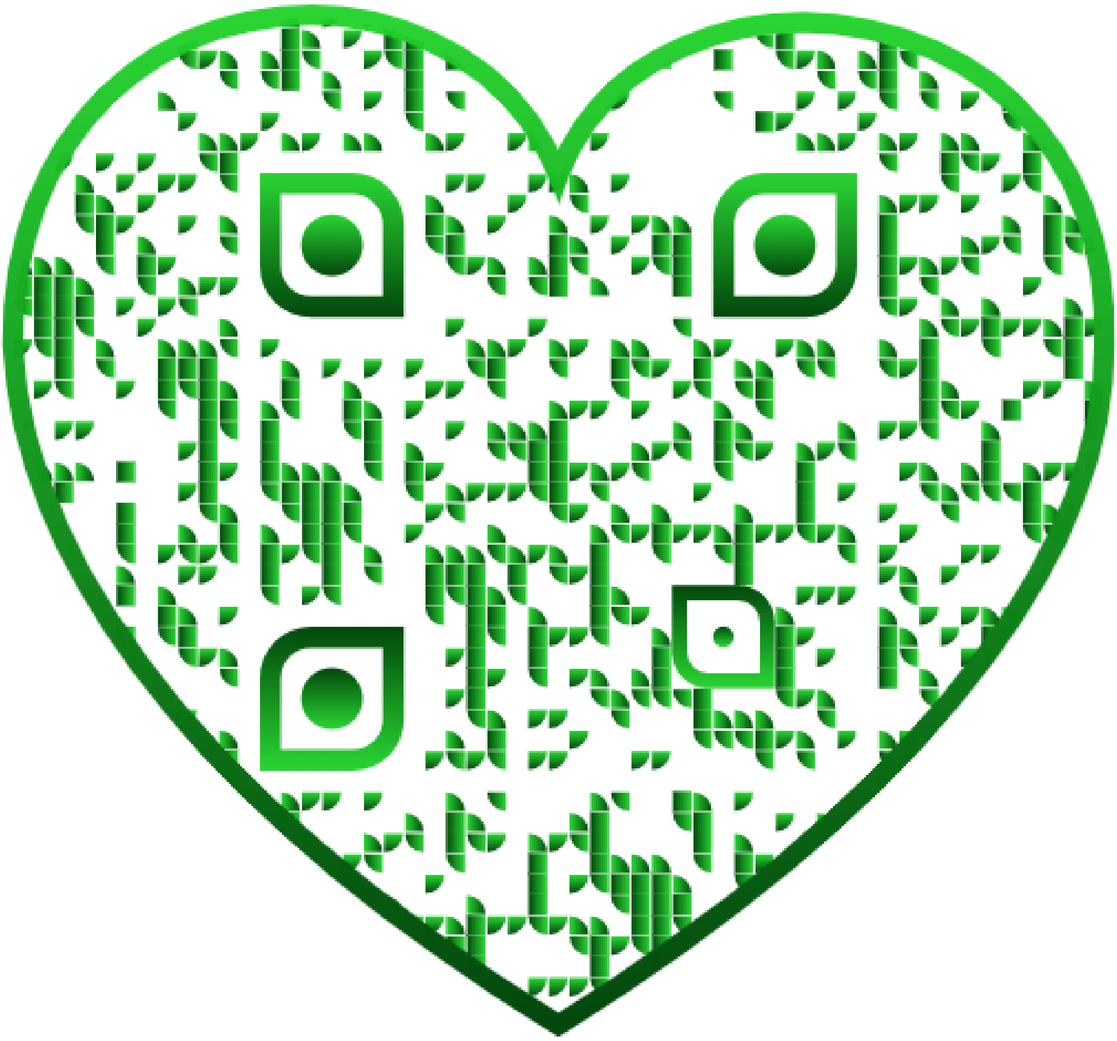

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FROM THE EDITOR

On the eve of a quarter century, it seems like a good time to pause and take a look back (and forwards) at the science that matters. Of course, it's all important, but it's fun to wind the clock back and argue about the breakthroughs that have really blown our minds since the year 2000.

I think my answer is rather dull sadly, but I can't see past it: the smartphone. Yes, the first device you could call a smartphone arrived in the 90s, courtesy of IBM. But the one really bearing a resemblance to the handsets of today took root in 2008 (in the UK at least) with the arrival of the G1 (Google's first Android phone), Apple's iPhone and the 3G networks to support them.

What's truly significant for me is how the smartphone empowers the curious to explore the world. In my garden I can take a photo of any flower, and upload it to one of dozens of identification apps and, in an instant, I have a name. With that name comes a torrent of information: what it is, where it's from, the kind of soils and light it prefers, and so on. At night I can point my phone skywards and discover that the bright, orange-hued object that caught my eye, is in fact Mars. I can travel the world without much of a plan, speak to locals and read signs with translation apps and find practically anything I need, all via a smartphone. It's easy to take for granted, but as a conduit for knowledge, the smartphone is unparalleled.

Thankfully, we also asked some of the world's leading scientists and science commentators for their take on the biggest breakthroughs of the 21st century (so far), and they provided some much more interesting answers, starting on p38. Of course, our list is by no means exhaustive, so please let us know what we missed at **reply@sciencefocus.com**.

Daniel Bennett

Daniel Bennett, Editor

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Dr Chris van Tulleken reveals whether you can eat upside down and how the trillions of bugs in your stomach influence you.
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The Reith Lectures
Forensic psychiatrist Dr Gwen Adshead asks whether we need to rethink prison systems and the way we view violent offenders in the future?
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Sliced Bread
Our favourite radio series returns to investigate the promises made by products. To kick things off, Greg finds out whether hair-loss treatments can ever do what they claim.
Listen now on BBC Sounds

If I travelled really far back in time, would I still be able to breathe? →p84

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Many of us use cosmetics to spruce ourselves up. But could they contain chemicals that potentially harm our health? Environmental scientist Iseult investigates. →p33

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DR CHRISTIAN JARRETT

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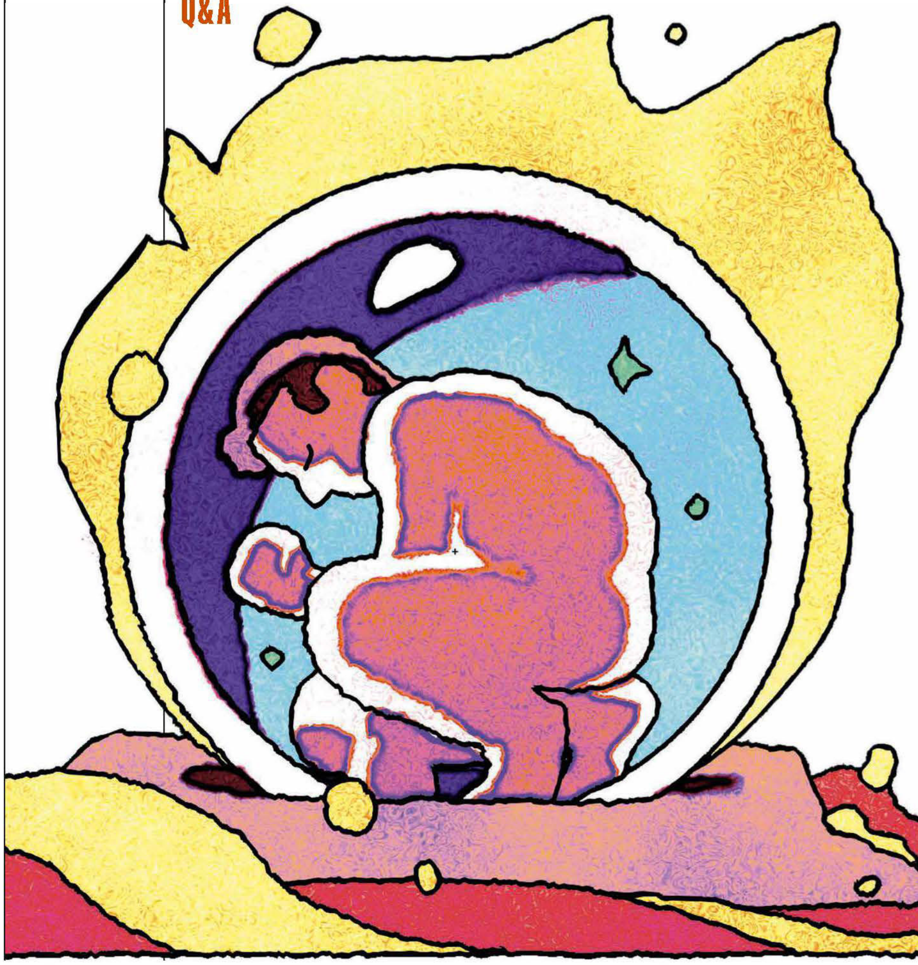

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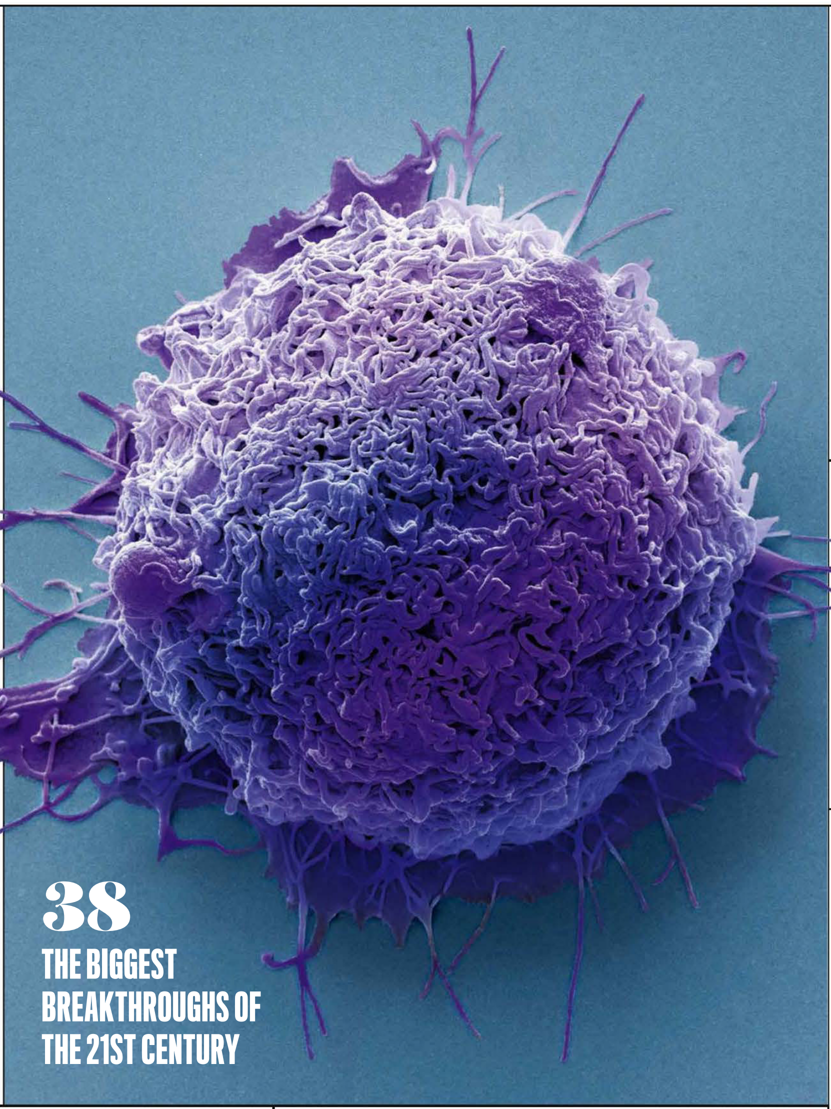

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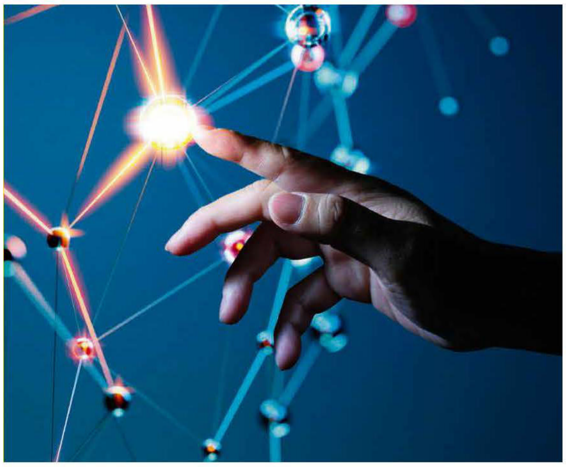

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PROF MICHAEL BOHLANDER

✕

"WHETHER WE'RE ALONE IN THE UNIVERSE IS NOT A MATTER OF NATIONAL SECURITY"

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THE BIGGEST BREAKTHROUGHS OF THE CENTURY
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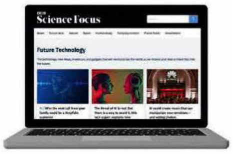

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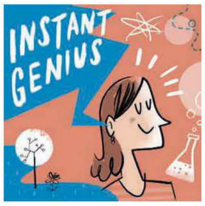

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IMAGES OF THE CENTURY

THE WORLD IS FULL OF WONDERS, AND HIGH-RESOLUTION CAMERAS LET US SEE THEM IN UNPRECEDENTED DETAIL. CHECK OUT OUR FAVOURITE IMAGES CAPTURED DURING THE FIRST 25 YEARS OF THE 21ST CENTURY

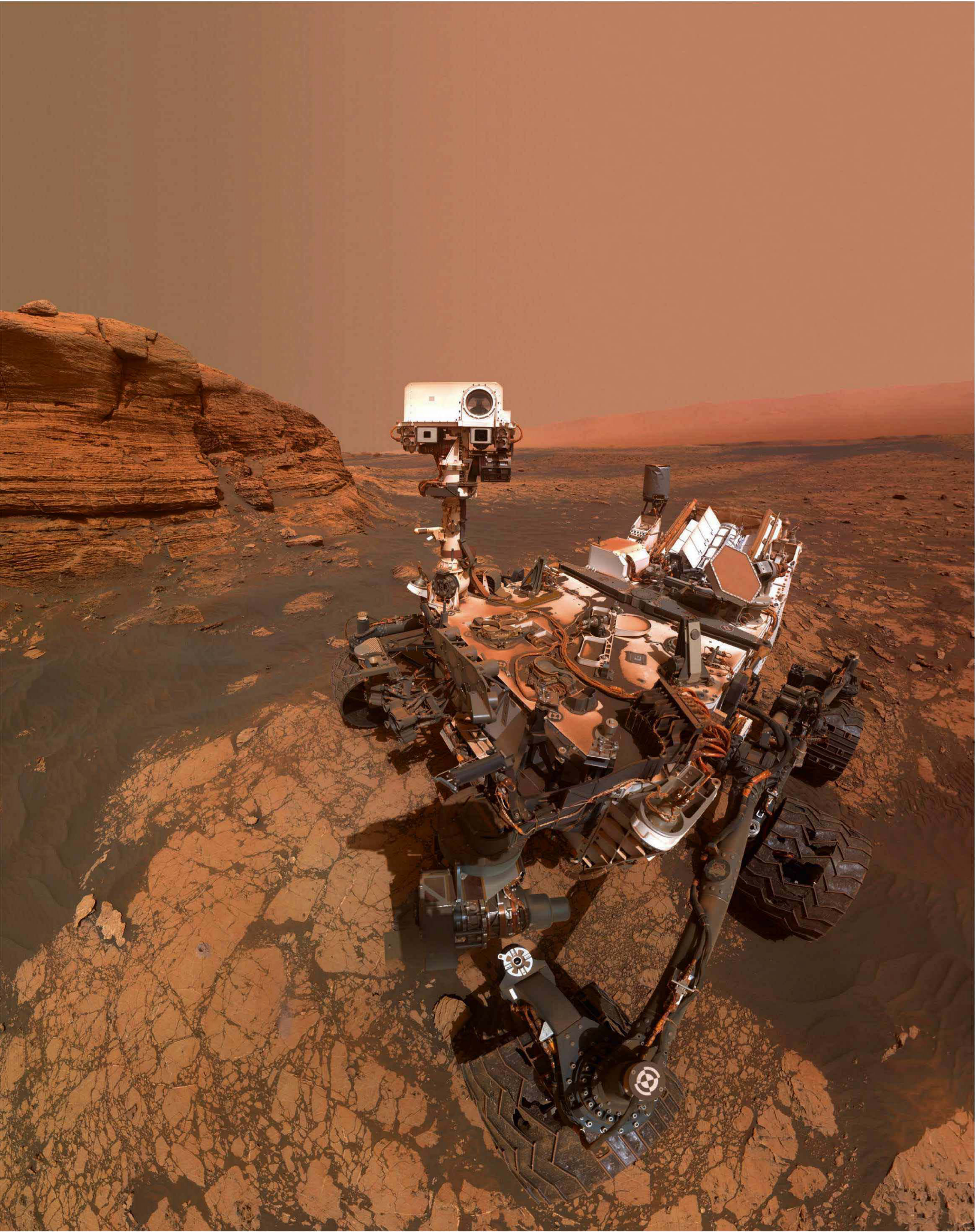
WORDS: HAYLEY BENNETT

BEST. SELFIE. EVER.

MONT MERCOU, MARS
2021

Launched in 2011, NASA's Curiosity Rover was sent to search for signs that life could have existed on Mars. It has now spent well over a decade on the Red Planet, carrying out experiments with its onboard laboratory. While Curiosity isn't heading back to Earth any time soon, the take-home message from its Martian campaign is that the planet once had free-flowing water and the kind of chemistry suitable for supporting life, namely microbes. One of Curiosity's most memorable moments came in 2021, when the six-wheeled wanderer took this cheeky selfie while posing on a small outcrop of rock that scientists named Mont Mercou, after the French mountain. It's perhaps not quite the 'moment' that it first appears, though. To create the selfie, scientists had to composite 60 images taken over two days with two cameras – most by using a robot arm like a selfie stick and the remainder using the 'Mastcam' on Curiosity's head.

NASA/JPL



MUMMIFIED MAMMOTH ↓

THE YUKON, CANADA

2022

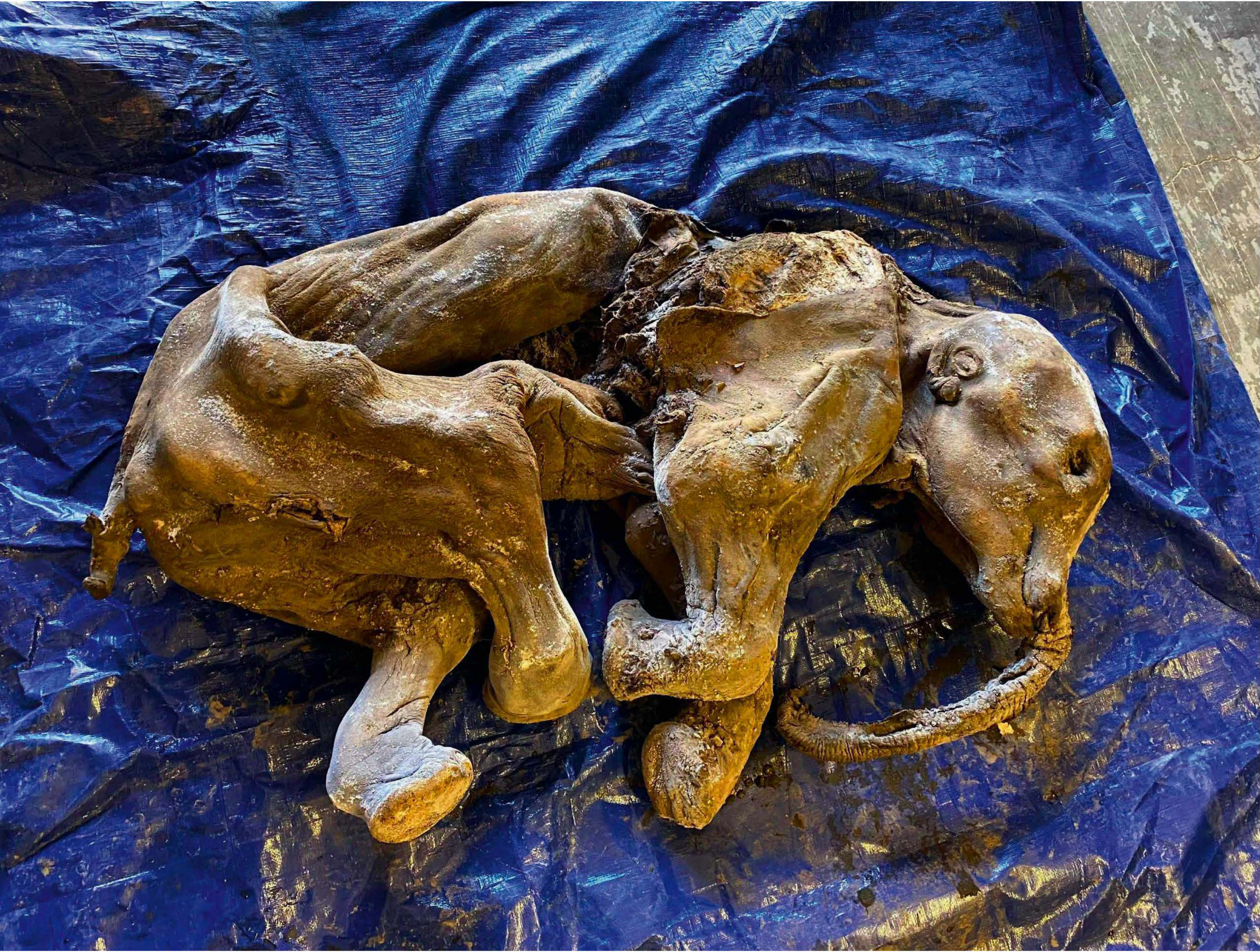
This is Nun Cho Ga, the only whole baby woolly mammoth to have been discovered in North America (near Dawson City, Yukon) to date. In the Hän language spoken in the region where her mummified remains were found, her name means 'big baby animal'. Nun Cho Ga was preserved in permafrost for 30,000 years before gold miners found her and handed her over to the Tr'ondëk Hwëch'in First Nation and Yukon governments. In 2024, she was moved to the Canadian Conservation Institute to be carefully preserved.

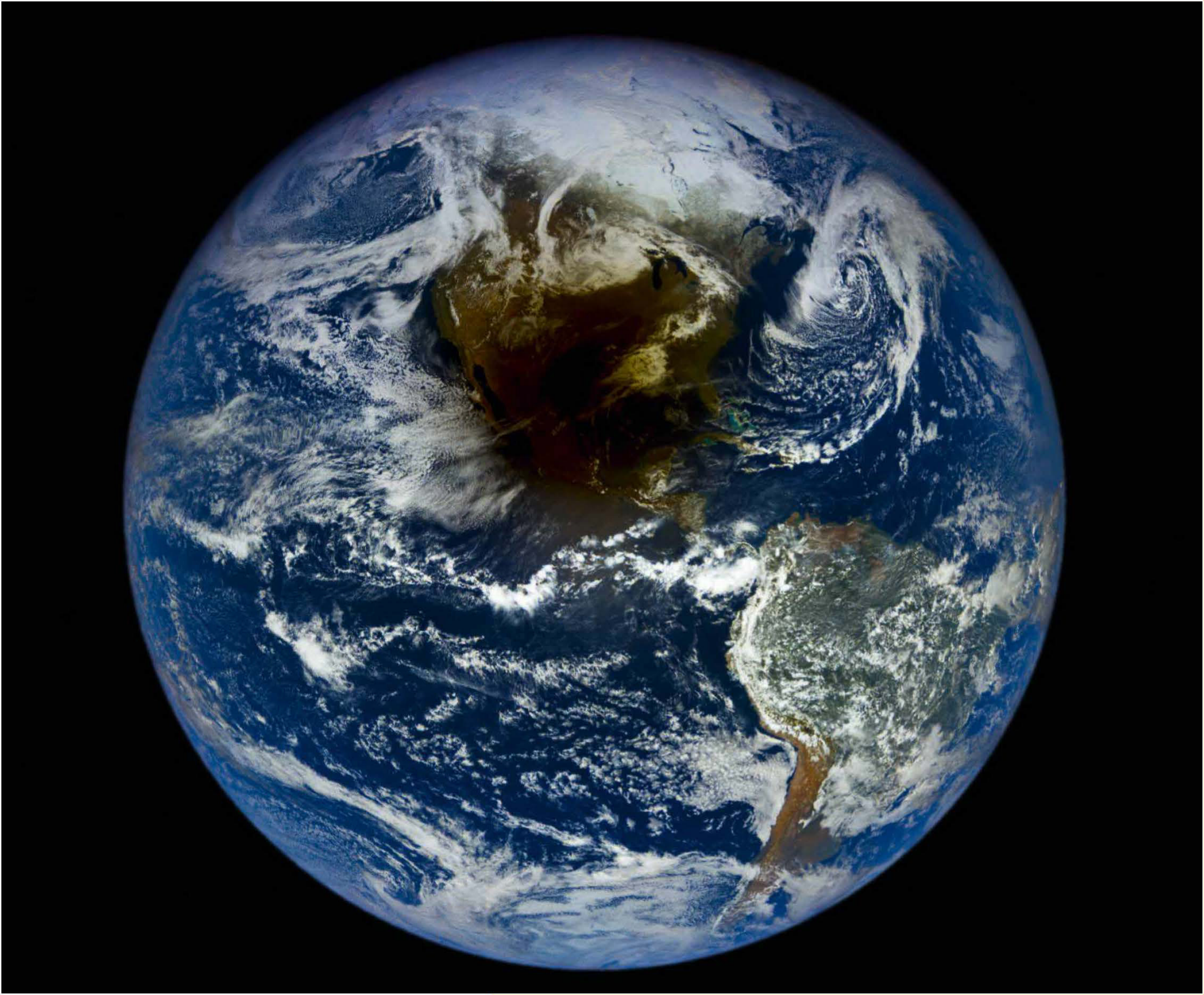
LOST IN THE SHADOWS →

AMERICA (FROM THE DEEP SPACE CLIMATE OBSERVATORY)

2024

A total solar eclipse happens only once every year and a half, and not everyone on Earth experiences a total eclipse each time – only those along a band called the 'path of totality'. This is where the Moon's shadow tracks briefly across Earth. On 8 April 2024, Americans across 13 US states experienced totality. This image of the Moon's shadow was captured by the Earth Polychromatic Imaging Camera (EPIC) housed in the Deep Space Climate Observatory satellite. America, say "Cheese!"



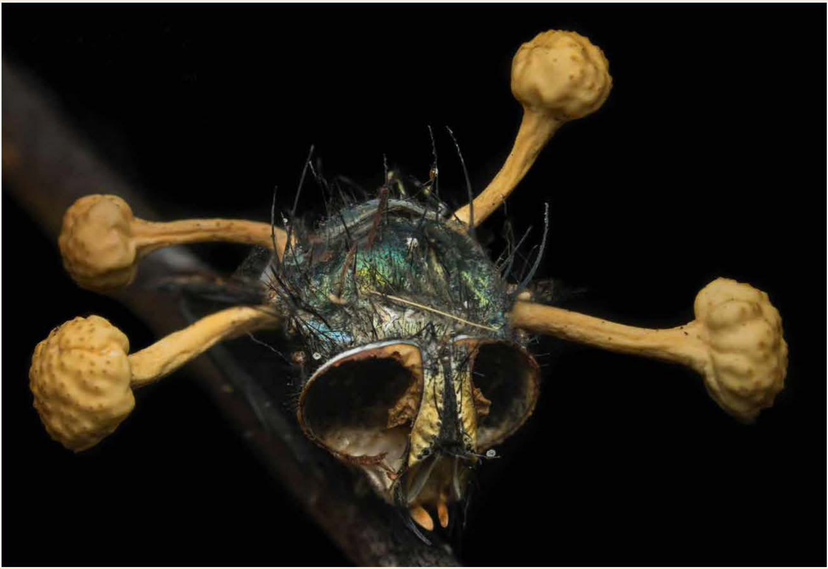


OUT OF HIS HEAD →

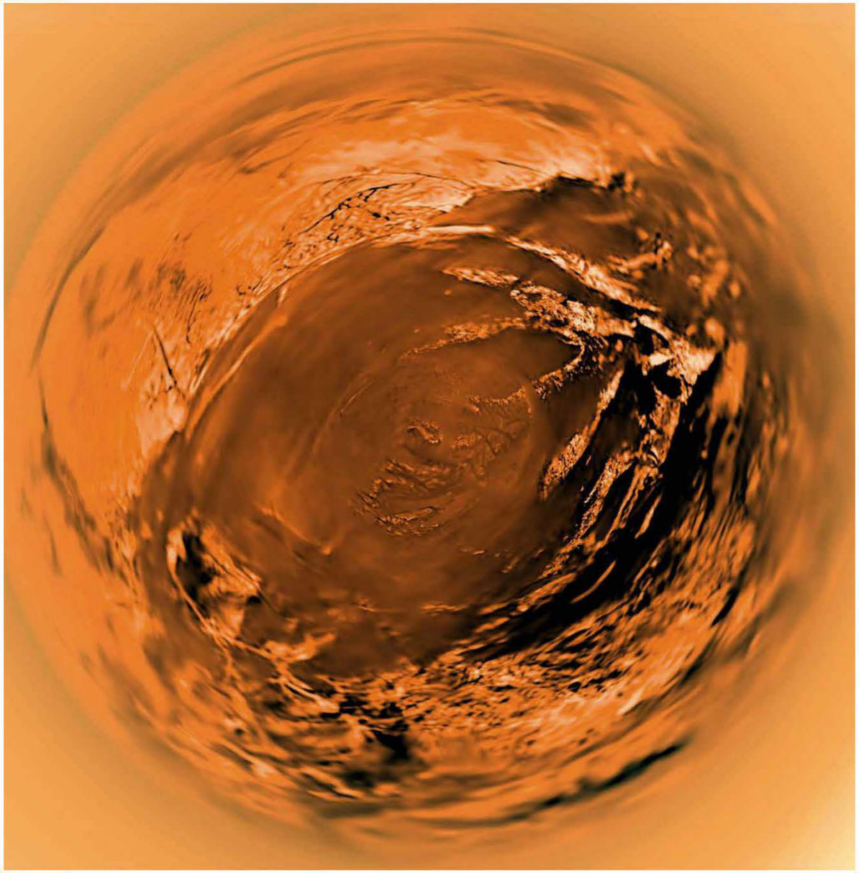
SINGAPORE

2017

It's hard to find any sympathy for flies, but try to spare a thought for this ill-fated fellow, who has vacated his skull following colonisation by the parasitic 'zombie fungus'. Cordyceps (*Ophiocordyceps unilateralis*) fungi infect and take over the minds of their insect victims, which are generally ants, but also flies. The fungi don't seem to infect their victims' brains directly; instead, they release mind-controlling molecules to do their bidding. Infection ends with the hapless insect climbing to the fungus' ideal sporing height, where it bursts through the insect's skull.



NASA/JPL, FAIZ BUSTAMI/MIRRORLESSMACRO, TR'ONDËK HWËCH'IN GOVERNMENT



GHOSTS IN THE MACHINE →

GENEVA, SWITZERLAND

2017

How do you catch a particle that travels at near-light speed and weighs virtually nothing? That's what this huge, gold, waffle-surfaced box is designed to do. Constructed between 2016–2018 at the CERN facility in Switzerland, the Deep Underground Neutrino Experiment (DUNE) is one of two prototypes for larger, US-based versions being built to detect fundamental particles called neutrinos (also known as 'ghost particles'), which originate from the nuclear reactions occurring within stars. The chamber acts as a Thermos flask for liquid argon, which boils at very low temperatures, so must be held below -184°C (-299.2°F). It contains detectors that can capture traces of the electrons released when neutrinos hit argon atoms. While neutrinos don't interact with much – trillions pass through us every minute with seemingly no effect – the density of atoms in liquid argon makes their interactions easier to sense. When operational, the new full-size chambers (20 times bigger than DUNE's) will hold 72,000 tonnes of argon and be able to detect beams of neutrinos fired from test facilities 1,300km (almost 810 miles) away. Scientists hope the chambers will help them fit neutrinos into the particle puzzle.

TOUCHDOWN ON TITAN ↑

TITAN (FROM THE HUYGENS PROBE)

2005

"We'll soon be landing in Adiri. The weather is breezy with temperatures of -170°C (-274°F)." We can imagine space tourists one day hearing these words as they prepare to disembark at a spaceport on Titan, Saturn's largest moon. As of now, though, the Huygens probe remains the moon's only visitor from Earth – mainly because getting there is such a chore. Having departed at the end of the 20th century – October 1997 – aboard the Cassini spacecraft (see 'Basking in the Sun's glow', p16), it took the robotic lander until January 2005 to begin its descent to Titan's surface. As it parachuted into the moon's Adiri region, Huygens took a number of photographs, including this one, before making a soft landing in sand and dirty ice. Thanks to the lander's (strictly business) trip, we now know that Titan's atmosphere contains complex organic compounds and its surface is scarred with dried-out rivulets of what may have been liquid methane.

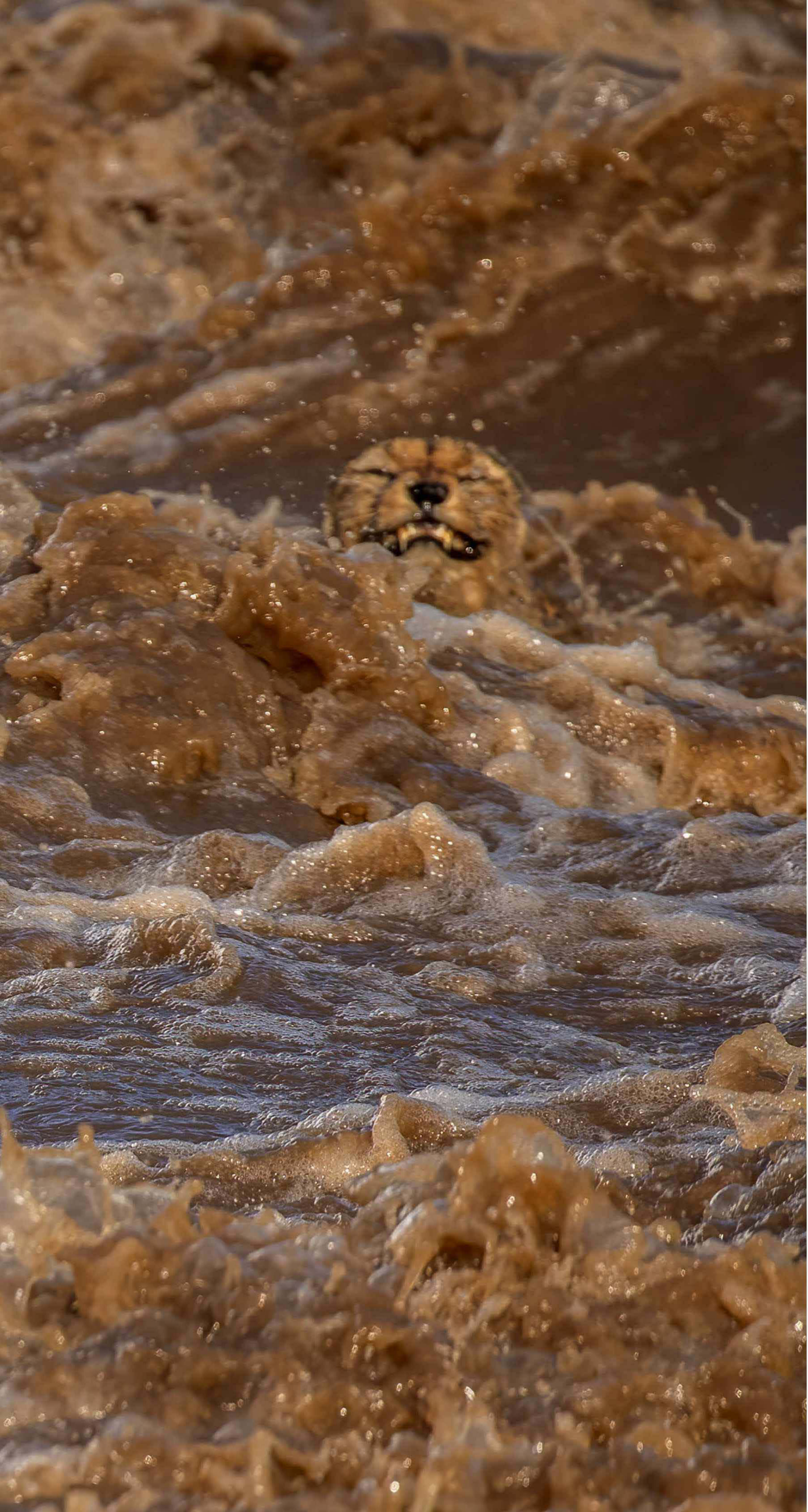
HEAD IN THE CLOUDS →

11,000M (36,000FT) ABOVE THE PACIFIC OCEAN

2016

Santiago 'The Storm Pilot' Borja has received many plaudits for the pictures he takes from the cockpit of his Boeing 767 passenger plane. He initially tried taking photos of mountains and cities, but realised they were too small to appreciate from the air. So he switched to taking photos of the weather instead, often using lightning to illuminate the scenery. Although he uses relatively long exposures, his photos aren't blurry: the lightning works as a fast flash. This atmospheric image focuses on an 'overshooting top' – a patch of cloud where strong updraughts in a thunderstorm have caused a protrusion from the top of a cumulonimbus. They're small in meteorological terms, measuring around 15km (about nine miles) across. Textbook examples appear as distinct spots in infrared satellite imagery. Overshooting tops are important in meteorology because they mark the location of the most severe conditions in storms.

NASA/JPL, CERN, SANTIAGO BORJA



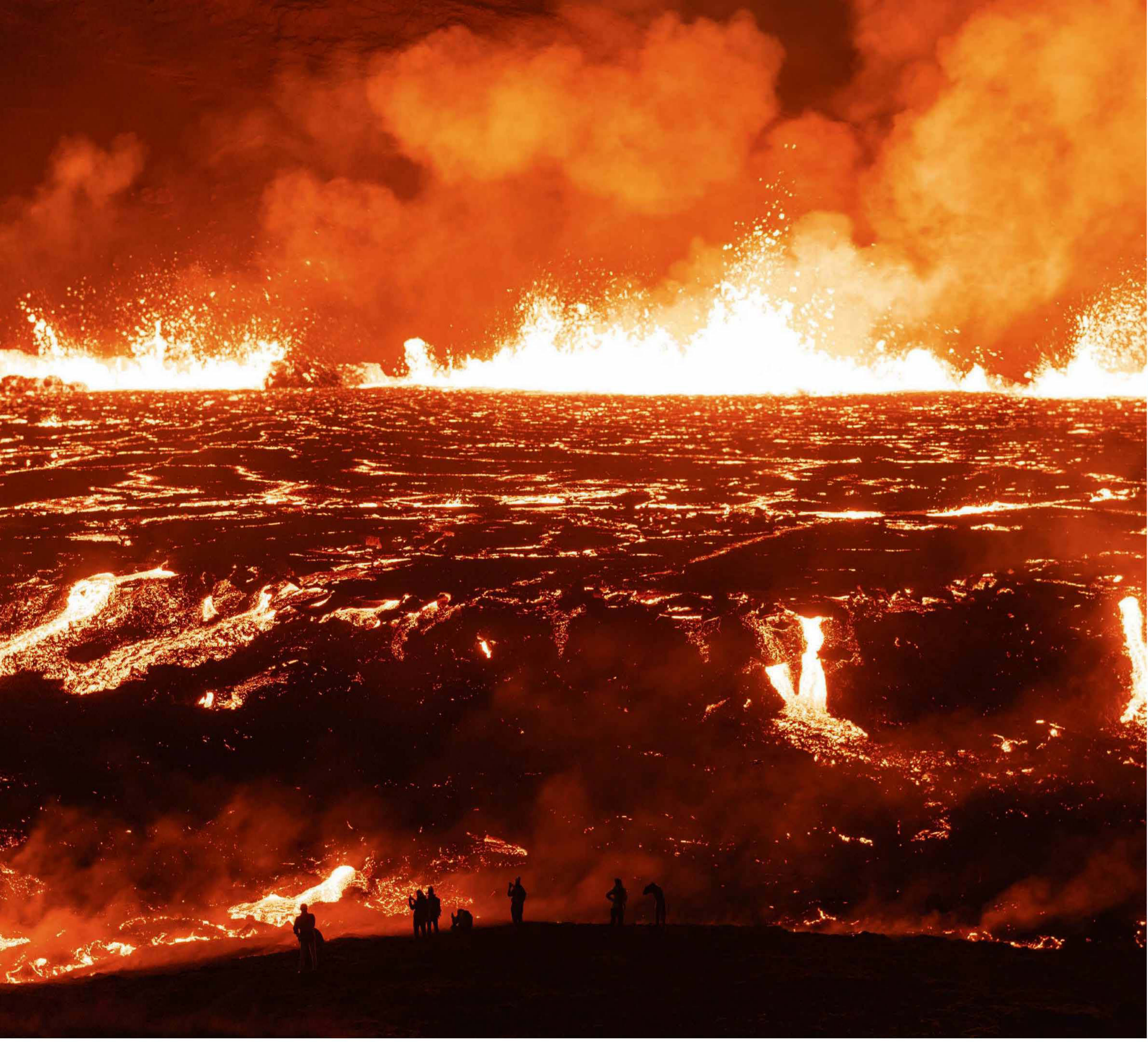
SINK OR SWIM

MAASAI MARA, KENYA

2020

The River Talek in Kenya is one of five tributaries that flow into the Mara River, which drains the famous Maasai Mara National Reserve. Home to elephants, wildebeest, rhinos and big cats, like these cheetahs, the Maasai Mara is a wildlife haven and safari destination. But when the region was inundated with flood waters in January 2020, the river burst its banks and there were fears that animal populations would be swept away – as one man was, while trying to cross a bridge over the river. The cheetahs in this image also faced a difficult crossing, though witnesses say they were lucky enough to survive. Meanwhile, camps in the Maasai Mara were flooded and some tourists had to be rescued after seeking refuge on rooftops. Unfortunately, the region continues to be hit by deadly flooding, which is attributed to climate change. In May 2024, the River Talek broke its banks once again, following a particularly intense rainy season. Around 200 people are thought to have lost their lives in flash floods and mudslides.

BUDDHILINI DE SOYZA



PLAYING WITH FIRE

REYKJANES PENINSULA, ICELAND

2022

Volcano tourism has exploded in recent decades, as thrill-seeking hikers flock to hotspots like the Hawaii Volcanoes National Park or the smoking craters of Mount Etna in Sicily. The risks of doing so aren't to be taken lightly, however. In December 2019, a tour group visiting the White Island in New Zealand was caught out when the volcano erupted, killing 22 of the 47 tourists. Still, when lava started spewing from the ground at the Reykjanes Peninsula in Iceland in 2021, some sightseers remained undeterred. Iceland is, of course, well-known for its volcanic activity, but this region is easily accessible from the capital, Reykjavik. In this photo, taken a year later, tourists are witnessing an eruption at a second location, about a kilometre away in the Meradalir Valley. Prior to 2021, there hadn't been much volcanic activity in the area since the 12th century, but now, new vents are opening up on a regular basis. In 2023, a 3km-long (1.8-mile) crack appeared not far from the fishing town of Grindavík, prompting 3,800 people to leave their homes. Many have yet to return.

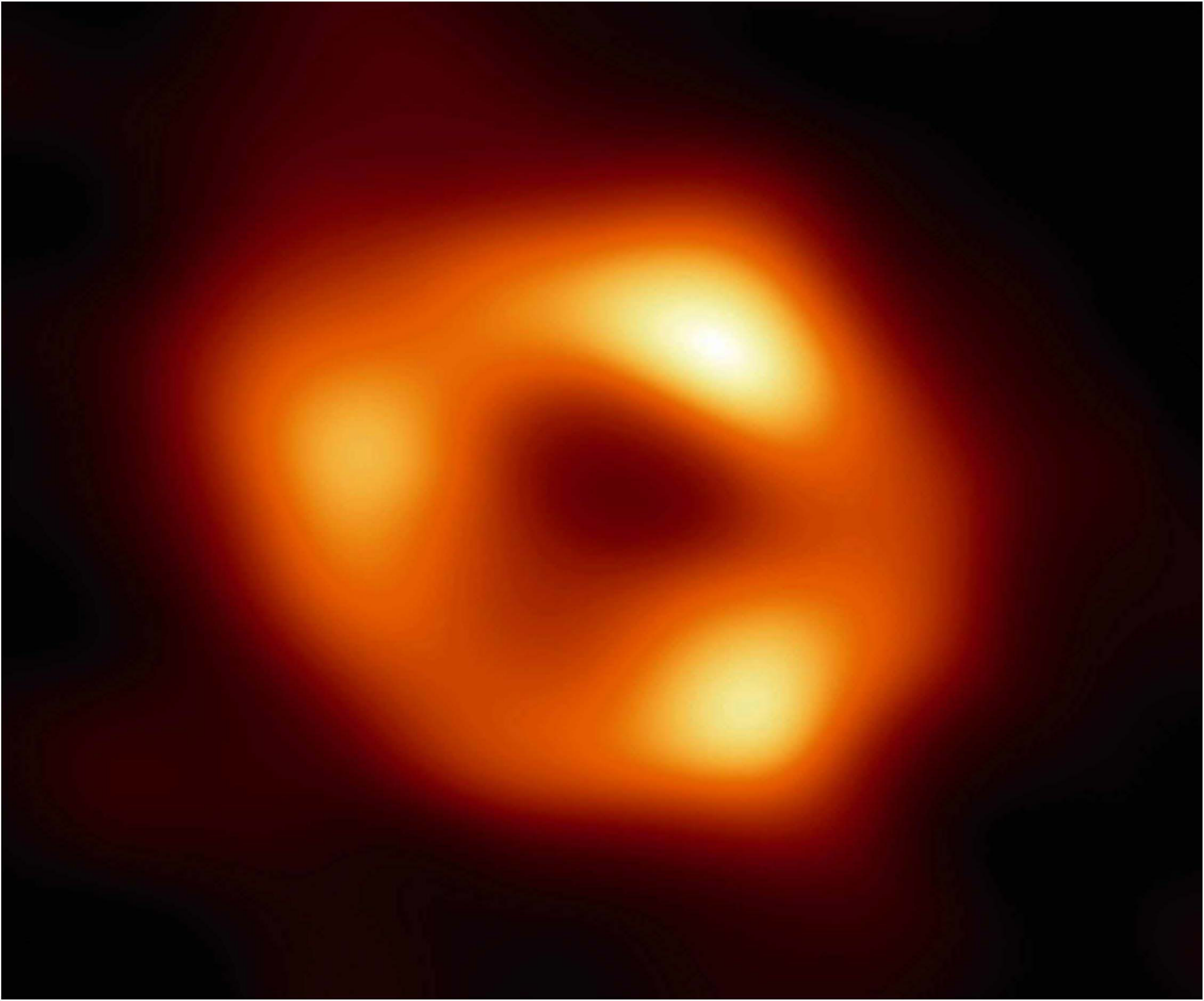
"PRIOR TO 2021, THERE HADN'T BEEN MUCH VOLCANIC ACTIVITY IN THE AREA SINCE THE 12TH CENTURY"

CENTRE OF ATTRACTION

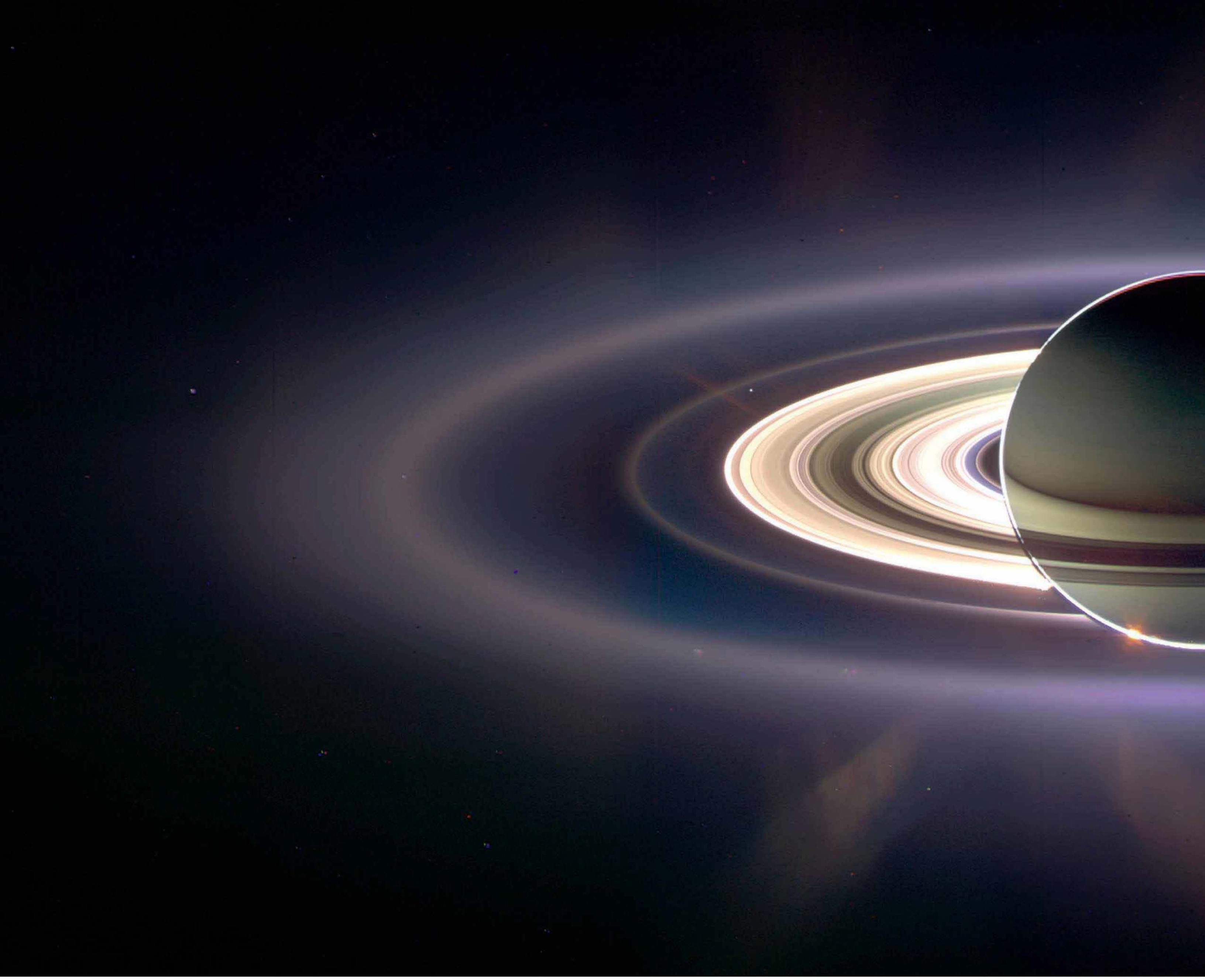
SAGITTARIUS A* (FROM EARTH)

2022

We first stared into the astronomical abyss in 2019, when the international team of scientists working at the Event Horizon Telescope (EHT) captured an image of M87*, a supermassive black hole in the centre of a galaxy 53 million light-years from Earth. Three years later, the EHT team used its global array of telescopes to produce this composite image of Sagittarius A*, the supermassive black hole that lies 26,000 light-years away at the centre of the Milky Way – our home galaxy. In this image and the image of M87*, it's not the black holes we see, but the glowing gases swirling around them. Even though it's considerably closer, it was much harder to get a clear shot of Sagittarius A* because of its lower mass. At 'only' 4 million times the size of the Sun, it's a baby compared to M87*, which is a whopping 6.5 billion times bigger than the star at the centre of our Solar System. This size discrepancy means the gases swirl around Sagittarius A* within minutes, as opposed to days at M87*, making for a changing pattern of brightness that's difficult to image. EHT scientists are now working to produce the first movie of a black hole, after the 15m-wide (49ft) Africa Millimetre Telescope in Namibia was added to the array.



ODYSSEAS CHLORIDIS, EHT COLLABORATION



> “ALTHOUGH THEY LOOK SMOOTH AND CONTINUOUS, THE RINGS ARE ACTUALLY FORMED FROM BILLIONS OF PIECES OF ICE AND ROCK”

BASKING IN THE SUN’S GLOW

SATURN (FROM THE CASSINI SPACECRAFT)

2006

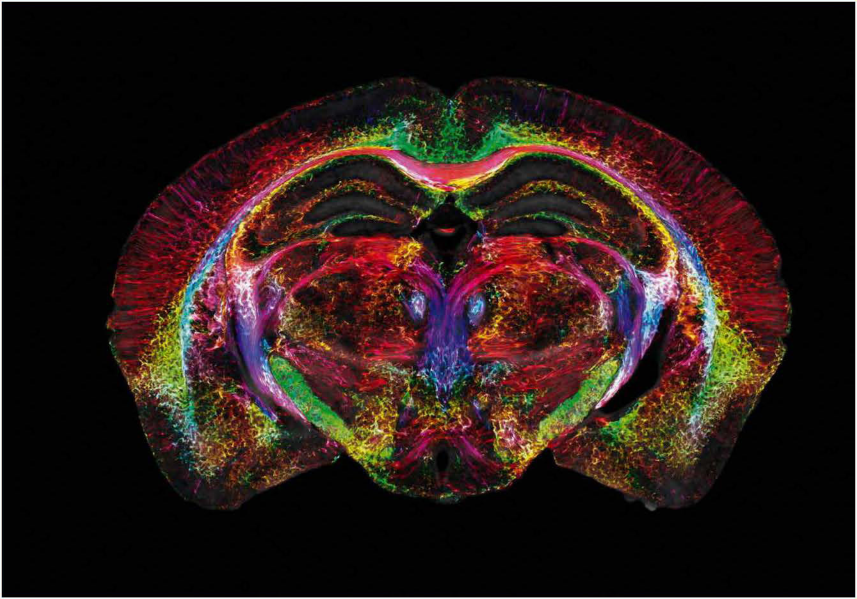
NASA launched its Cassini spacecraft from Cape Canaveral, Florida, in 1997. Seven years later, it reached Saturn, its primary destination, having travelled 3.4 billion kilometres and taken in the sights of Jupiter along the way. Upon its arrival at Saturn, the spacecraft embarked on a grand tour of the ringed planet’s many moons, including Titan (where it dropped off the Huygens lander – see p10), Dione, Enceladus and Rhea. In total, Cassini collected 453,000 images during its mission, including this stunning portrait of Saturn, taken as the planet occulted the Sun. Saturn’s rings were discovered over 400 years ago by Galileo, but, backlit like this, they appear brighter and perhaps more beautiful than we’ve ever seen them. Although they look smooth and continuous, they’re actually formed from billions of pieces of water ice and rock – some as small as grains of rice, some as big as mountains. With the information Cassini was able to gather, scientists were able to learn more about where this material comes from. For instance, we now know that many of the icy chunks in the E-ring – one of the fainter, outer rings – were vented from Enceladus.

RECORD-BREAKING RESOLUTION

NORTH CAROLINA, USA

2023

This is a slice through a brain scan that's 64 million times sharper than any ordinary magnetic resonance imaging (MRI) machine is capable of producing. The full, 3D version – unveiled in 2023 on the 50th anniversary of the invention of magnetic resonance imaging – allowed scientists to view mind-boggling details of the circuitry inside a mouse's brain. It's the result of four decades of work at Duke University's Center for In Vivo Microscopy. Researchers there plan to use ultra-high-resolution scanning to study brain tumours and get to grips with what's really going on in neurodegenerative conditions like Alzheimer's disease.



NASA/JPL, DUKE UNIVERSITY

BIG MACHINE SEEKS SMALL PARTICLES ↓

GENEVA, SWITZERLAND

2005

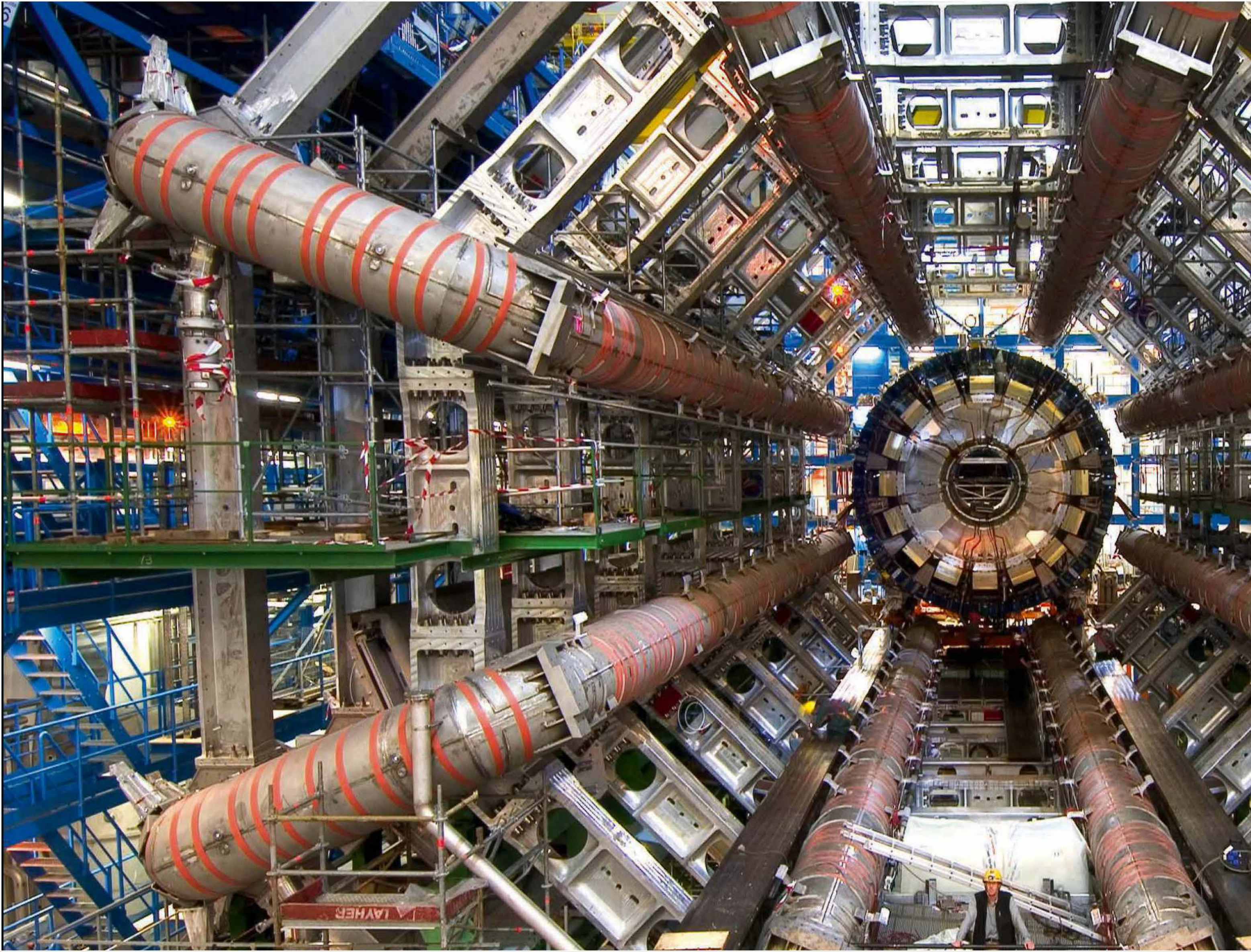
ATLAS is the world's biggest particle detector, housed at the CERN facility in Switzerland. It catches fallout from the Large Hadron Collider (LHC), which fires beams of high-energy particles at each other inside a 27km (almost 17 miles) doughnut-shaped tunnel under Geneva. This image was taken before the final pieces were lowered in and the LHC was powered up. Following its detection of the Higgs boson in 2012, scientists began upgrading ATLAS. In 2020, two new detectors were installed that can pinpoint the position of a muon particle to within a tenth of a millimetre in less than one 400,000th of a second.

CALIFORNIA BURNS →

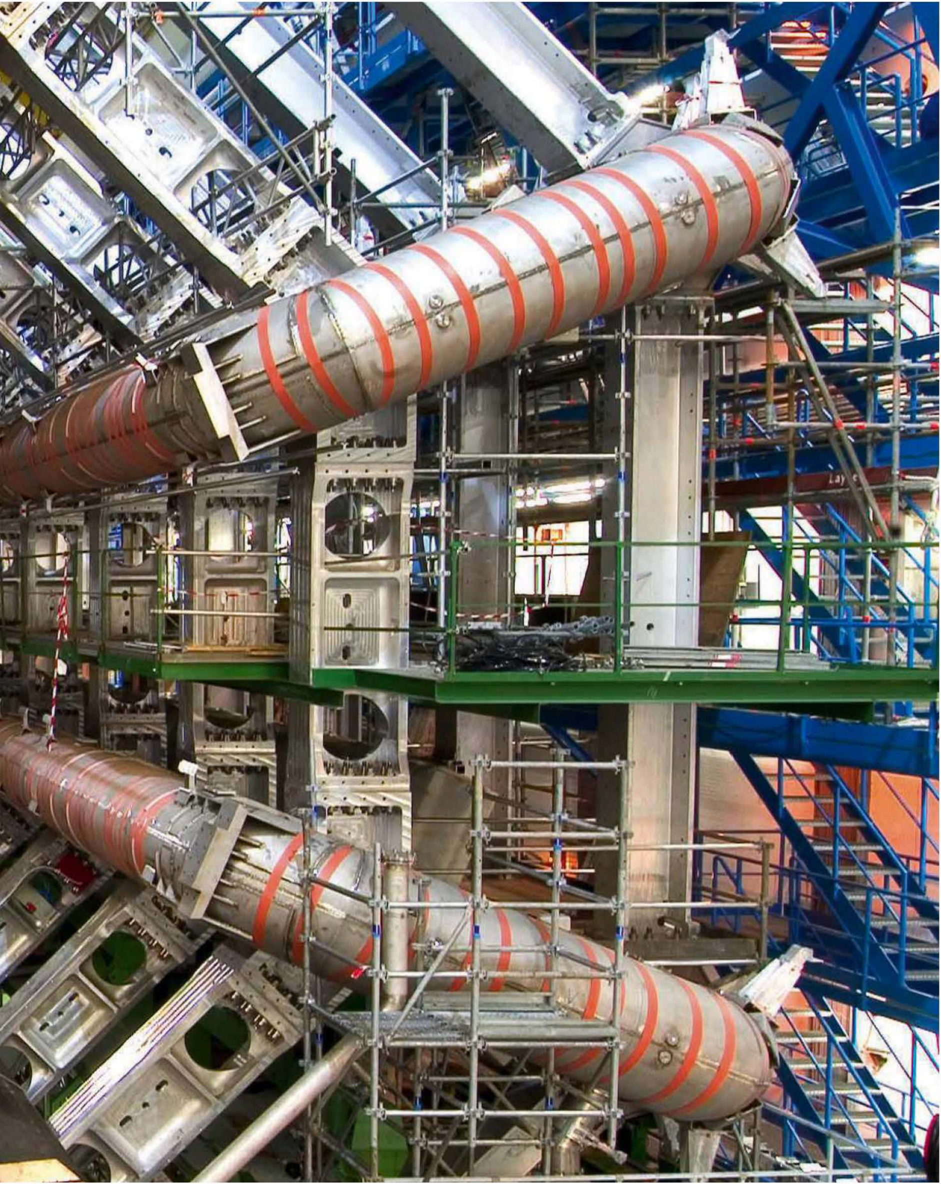
VENTURA COUNTY, CALIFORNIA

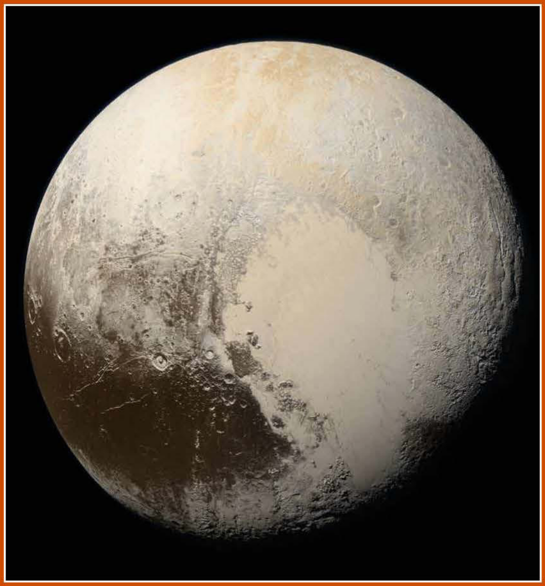
2019

In 2019, wildfires raged across 1,122km^2 (697 sq miles) of California. The 'Maria' fire (right) engulfed 16km^2 (10 sq miles) of Ventura County before firefighters could put it out. More than 10,000 people evacuated their homes as it rampaged through the region just northwest of Los Angeles, all while firefighters across California battled other large blazes. But 2019 was a 'good' year for California – the average area consumed by wildfires is currently closer to 4,000km^2 (2,485 sq miles). The California Air Resources Board says hotter, drier conditions driven by climate change are increasing the frequency and severity of wildfires.



ALAMY, NASA/JPL, CERN





PLUTO, UP CLOSE

PLUTO (FROM THE NEW HORIZON'S SPACECRAFT)
2015

When NASA launched its New Horizons spacecraft in 2006, Pluto was still a planet and the only one in the Solar System that remained completely unexplored. Later that same year, however, Pluto lost its full planet status as the International Astronomical Union officially designated it a 'dwarf planet'. This may have downgraded the importance of the mission, but it didn't change its trajectory. New Horizons was already past Mars and well on its way towards Jupiter, taking advantage of a gravity assist by the gas giant to knock three years off its journey time. Finally, in July 2015, the spacecraft passed within an astronomical hair's breadth – 12,553km (7,800 miles) – of Pluto, using its telescope to take the photo above. Prominent in the centre-right of this image is the Solar System's biggest glacier, Sputnik Planitia, first spotted by the Sputnik 1 satellite in 1957 and measuring around 1,000km wide (621 miles). Thanks to data from the flyby, scientists were able to conclude that Pluto is bigger than they thought, although it's not actually size that determines planetary status. The issue for Pluto is that its gravity isn't strong enough to have cleared 'its neighbourhood' of other objects.

by **HAYLEY BENNETT** *(@gingerbreadlady)*
Hayley Bennett is a science writer based in Bristol, UK.

This was Sylvia's promise to you...

A generation ago, a woman named Sylvia made a promise. As a doctor's secretary, she'd watched stroke destroy the lives of so many people. She was determined to make sure we could all live in a world where we're far less likely to lose our lives to stroke.

She kept her promise, and a gift to the Stroke Association was included in her Will. Sylvia's gift helped fund the work that made sure many more of us survive stroke now than did in her lifetime.

Sylvia changed the story for us all. Now it's our turn to change the story for those who'll come after us.

Stroke still shatters lives and tears families apart. And surviving a stroke is just the start of a long and gruelling recovery journey. If you or someone you love has been affected by stroke – you'll know just what that means.

You can change the story, just like Sylvia did, with a gift in your Will. All it takes is a promise.

You can promise future generations a world where researchers discover new treatments and surgeries, and stroke survivors and their families have the support to find the strength and determination they need to find their way back to life.

Your promise today gives strength for tomorrow. Please, leave a gift in your Will to the Stroke Association.

Find out how by calling 020 7566 1505
or email legacy@stroke.org.uk
or visit stroke.org.uk/legacy

Finding **strength** through **support**

Stroke
Association

The Stroke Association is registered as a charity in England and Wales (No 211015) and in Scotland (SC037789). Also registered in the Isle of Man (No. 945) and Jersey (NPO 369), and operating as a charity in Northern Ireland.

FEEDBACK

YOUR OPINIONS ON SCIENCE, TECHNOLOGY AND OUR MAGAZINE

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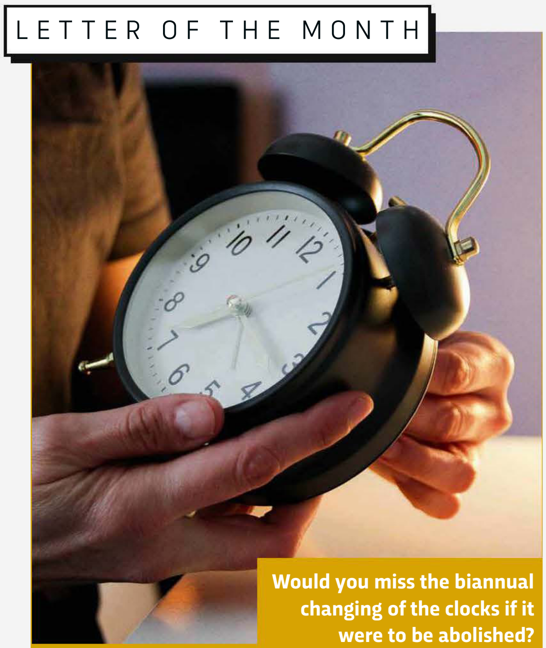
LETTER OF THE MONTH



Would you miss the biannual changing of the clocks if it were to be abolished?

Turn back the clock

Ian Taylor's 'Should we scrap daylight saving time?' (November, p76) was interesting. Older readers may remember the experiment of 1968–1970 when British Summer Time was rebranded as British Standard Time and retained throughout a three-year period with no spring or autumnal changes.

It sticks in my mind because it coincided with my move to secondary school. From memory, the whole experiment went down like a lead balloon and there was a huge, nationwide sigh of relief when it ended.

Okay, society might well have changed since then, but probably not enough to invalidate the conclusions. At least, that's my opinion.

David Schaffert, Tewkesbury

WRITE IN AND WIN!

The writer of next issue's Letter of the Month wins a pair of popular science books: **The New World on Mars** *and* **Into the Groove**.

WORTH OVER £20
MARS
Into the groove

GETTY IMAGES X2, ALAMY

Rain, rain, go away

There's obviously too much water in our atmosphere at the moment, causing an immense amount of flooding around the world. My immediate thought is why can't we collect water in travel-worthy water butts and place the water back underground where a lot of it came from originally?

Surely there are empty underground lakes, or unused quarries and coal mines that could be filled? It wouldn't be cheap, but neither is the cost of rebuilding homes and lives when there's no guarantee the flooding won't happen again.

Heather, Hitchin

Is too much water is getting trapped above ground, instead of below it?

Mineral mistake

I enjoyed your news story 'Major volcanic eruptions detected on the Moon's far side' (December, p15). As a geologist, I must point out a misstatement, however. The article describes basalt as being a mineral. In actuality, basalt is an igneous rock made up of a suite of minerals. By definition, a mineral must have, among other requirements, a regular crystalline structure and a defined chemical composition. Basalt doesn't have a crystalline structure and its chemical compositions can vary depending on the source.

David de Gruyter, Alaska

Basalt, an igneous rock found on Earth, the Moon, Mars and Venus

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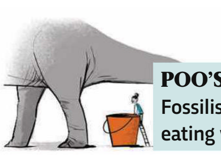


POO'S CLUES
Fossilised dino dung reveals who was eating who in the Triassic period **p24**

SCALE STORM
Scientists have discovered why hailstones are getting bigger **p25**

WAR OF THE WORDS
Abbreviations in text messages make you seem less sincere, say experts p27

NEWS FROM THE FRONTIERS OF SCIENCE

DISCOVERIES

GEOPHYSICS

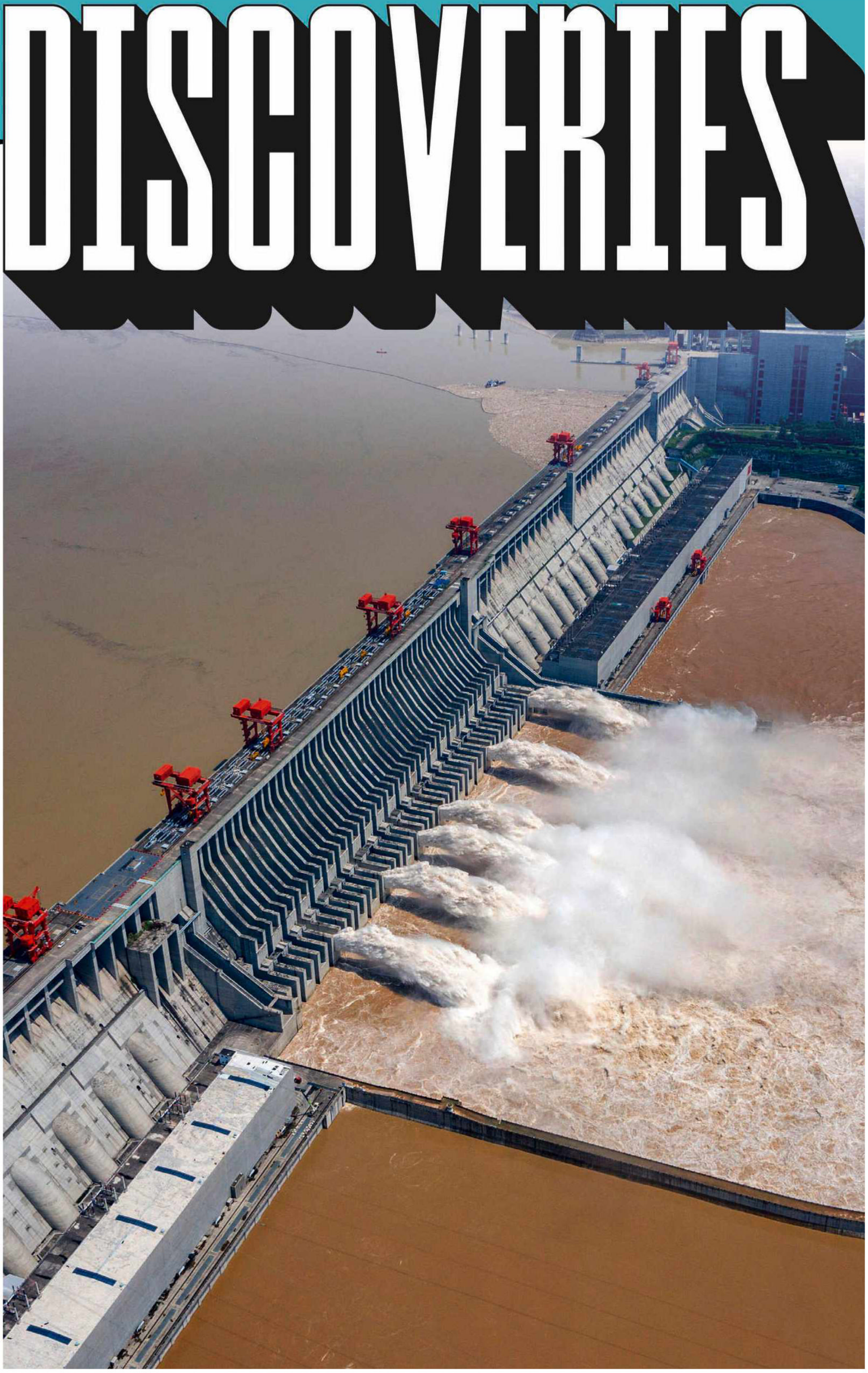
Human activity is changing Earth's tilt and rotation

Scientists have found that using underground water has more of an impact on Earth's tilt than melting polar caps

Even though we can't feel it, most of us are aware that our planet spins like a top during its interminable journey around the Sun. Rather than revolving about a vertical axis, however, Earth has always been off-kilter, spinning about an axis (or pole of rotation) that's tilted at 23.44°. The amount of tilt – also known as obliquity – is never constant, and displays natural short-term oscillations and longer-term cycles.

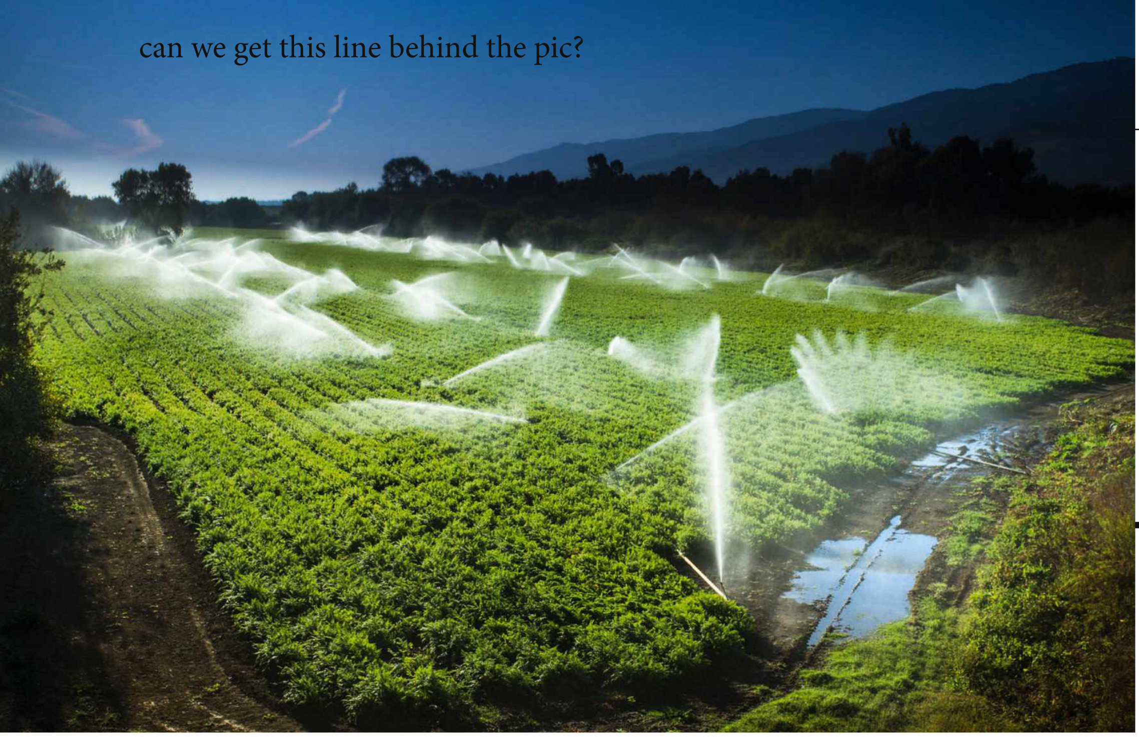
Earth's tilt can also be changed by shifting huge amounts of mass around the planet. And this is happening right now, on an extraordinary scale, due to us.

As global heating drives the melting of the polar ice sheets, it decants colossal volumes of water into the oceans. In a recent paper, scientists have revealed that this redistribution of mass is very slightly modifying the world's tilt.



ALAMY, GETTY IMAGES

can we get this line behind the pic?



LEFT Underground freshwater reserves are being drained to irrigate crops

OPPOSITE The Three Gorges Dam in China holds 40 billion cubic metres of water

> **"We can see our impact, as humans, on the whole Earth system"**

But there's more. In itself, polar melting isn't sufficient to account for all of the tilt change – something else has to be happening too. The answer, the authors of the paper say, is beneath our feet.

In recent decades, the world's ever-growing population has resulted in a huge increase in demand for freshwater, particularly for use in crop irrigation. This need has been largely met by sucking up an estimated 23 million cubic kilometres of groundwater that was once locked away in aquifers beneath Earth's surface.

The authors have shown that the tilt change can be completely explained if, over the period of study, a water mass of around 2,150 billion tonnes (equal to 2,150 cubic kilometres) was abstracted from aquifers and used in one way or another, before finding its way, ultimately, into the oceans.

As Prof Ki-Weon Seo, a geophysicist at South Korea's Seoul National University, and his co-authors, observe, it's "like adding a tiny bit of weight to a spinning top; Earth spins a little differently as water is moved around." Between 1993 and 2010, this transfer of water mass raised global sea levels by more than 6mm (0.2in), shifting the rotational pole by nearly 80cm (2.6ft).

DEEP IMPACT

Should we be worried? Such a tiny change in tilt isn't going to have an impact on the climate, so the answer should be no. On the other hand, this finding shows that how we live today, has a measurable impact on a planetary scale.

Prof Benedikt Soja of ETH Zurich in Switzerland noted in a recent interview that "we can see our impact, as humans, on the whole Earth system, not just locally, like the rise in temperature, but really fundamentally, altering how it moves in space and rotates."

One of the more outlandish claims of the denier community is that humanity is too puny to have any real effect on the climate and how Earth operates in general. But this latest evidence is another nail in the coffin of this dangerous idea.

In addition to modifying tilt, the redistribution of mass from polar regions into the ocean basins has also contributed towards slowing the planet's rotation. This is estimated to be happening at 1.3 milliseconds a century; a value that could more than double by 2100 if we fail to curb emissions.

Like a spinning figure skater throwing out their arms to slow down, this huge transfer of mass, from polar regions close to Earth's axis to the wide expanse of the world's oceans, will continue to slow the planet's rotation further.

Compounding prodigious volumes of water behind China's Three Gorges Dam (left) has had the same knock-on effect, slowing Earth's rotation and increasing day length by 60 billionths of a second.

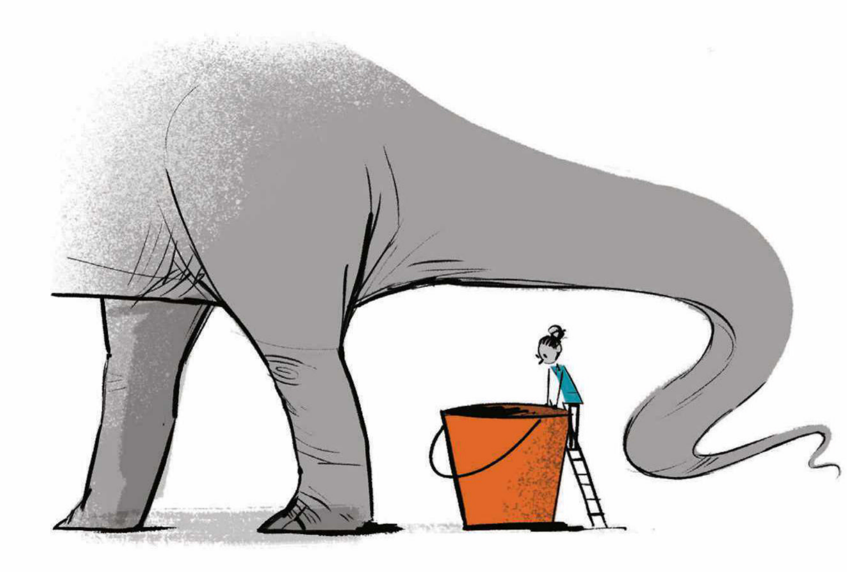
A MATTER OF TIME

While these changes don't have a detectable impact on our physical environment, they certainly present a challenge for electronic systems and networks predicated on accuracy and precise time measurement.

These include: the GPS that allows planes and ships to navigate, the algorithms that underpin today's financial markets and global timekeeping. When a 'leap' second was added to the world's atomic clocks in 2015, glitches were reported across multiple networks.

As groundwater aquifers are drained further, and polar melting continues, repeated tweaks to timekeeping and positioning systems – to account for new tilt and day length variations – will be essential to prevent their potentially catastrophic failures.

by **BILL MCGUIRE** *(@ProfBillMcGuire)*
Bill McGuire is professor emeritus of geophysical & climate hazards at UCL and author of Hothouse Earth: An Inhabitant's Guide



PALAEONTOLOGY

Poop and vomit reveals how dinosaurs got so big

It wasn't meat but plant-based diets that helped dinosaurs rise to the top

Dinosaurs enjoyed a long reign as Earth's dominant species, but for a long time, scientists wondered why it took them 30 million years to reach their apex status. Now, a new study of their fossilised faeces and vomit may have found the answer.

According to the study, published in the journal *Nature*, it was herbivore dinosaurs bulking up on plants that paved the way for the biggest dinosaurs, such as the sauropods and the carnivorous *Tyrannosaurus rex*.

The fossilised faeces and vomit (collectively known as bromalites) were dated to around 230–200 million years ago – about 100 million years before the reign of *T. rex*, and 150 million years before the Chicxulub asteroid hit Earth.

Using the bromalites, the scientists pieced together a 'food web' that essentially showed who ate who throughout the Triassic period and how the food chain evolved. They scanned over 500 fossils and found everything from beetles to bones and even half-digested fish in the fossils.

When researchers combined this information with climate data and other fossils, it revealed which animals and insects were roaming Earth alongside the dinosaurs.

"Sometimes, what look like unremarkable fossils contain remarkable information that can't be found elsewhere," Dr Martin Qvarnström, co-author of the study, told *BBC Science Focus*.

In the study, researchers scanned digestive material samples from south Poland. In the late Triassic, this would have been in the northern part of the Pangaea supercontinent. Around this time, experts believe there was a rise in volcanic activity and humidity, that ultimately led to more plant growth.

Dr Grzegorz Niedźwiedzki, co-author of the study, added: "Everyone hunts for fossilised skeletons, but it's the bromalites that tell the most about the dramas from millions of years ago."

HEALTH

Your cholesterol level predicts your dementia risk

People with stable levels have a lower risk of neurological conditions, says study

Scientists have discovered your cholesterol levels could be significantly linked to your risk of developing dementia. And it's not just high cholesterol that matters: fluctuating levels over several years could increase your chances of the disease by 60 per cent, suggests a new study of 10,000 people.

The research also suggests that, even if you don't develop dementia, a large cholesterol variability –

ILLUSTRATIONS: ADAM GALE

swinging from high to low levels – is linked to an increased risk of general cognitive decline by 23 per cent.

"Those experiencing big year-to-year variations … may warrant closer monitoring and proactive preventive interventions," said lead author Dr Zhen Zhou, a researcher at Monash University, in Australia.

In the study, the scientists considered the two main types of cholesterol. Firstly, the 'bad cholesterol' or low-density lipoprotein (LDL), which previous studies have shown can cause cardiovascular disease. They also examined 'good cholesterol' levels, which scientists refer to as high-density lipoprotein.

"Large annual fluctuations in LDL cholesterol (the 'bad' one) could lead to faster cognitive decline"

The research suggested huge annual fluctuations in LDL cholesterol (the 'bad' one) could lead to faster cognitive decline than in people with stable levels. Large swings of 'good' cholesterol were not found to impact the risk of cognitive decline, however.

In the US, just over one in four people have high levels of LDL, which health professionals define as over 130mg per decilitre (one-tenth of a litre) of blood. On the other end of the spectrum, they consider LDL levels below 100mg per decilitre as optimal, especially for people with diabetes or heart disease. Doctors can check your cholesterol levels with a simple blood test.

METEOROLOGY

Giant hailstones herald future storms

Study reveals how massive ice balls get bigger… and become lethal

Hailstones that are bigger than your fist plummeting towards the ground pose huge risks to people caught outside during hail storms. Now, a new analysis of these giant hailstones' inner structure reveals how they're able to get so big – a discovery which could help scientists predict hailstorms before they become a threat.

Hailstones are formed during storms, when a raindrop freezes in a very cold part of a cloud. They then grow in diameter as gravity pulls the increasingly heavy particles downwards.

For the new study, published in *Frontiers in Environmental Science*, a team of researchers from Barcelona and Catalonia (an autonomous region in northern Spain) collected giant hailstones up to 12cm (4.7in) in diameter and then used computed tomography (CT) scans to look inside them.

Usually, CT scans are used in more of a medical context – the rotating X-ray machine creates 3D images of people's bodies. But in this case, the machines – borrowed from a dental clinic – allowed researchers to study the 'anatomy' of the giant ice balls without breaking them apart.

Each cross-sectional image, known as a 'slice', of the hailstones revealed the density of the layers, showing how they grew at different stages of the storm. The researchers discovered that even the most spherical hailstones have irregular insides – in fact, strangely, the near-perfect-looking spheres had the most off-centre cores.

The researchers say this reveals that hailstones don't grow evenly in each direction, contrary to previous assumptions about hailstones – a discovery they think could help to predict violent storms before they happen and limit the damage they cause.

HEALTH

Key weight-loss mystery solved

New research suggests fat cells have a 'memory'

It's a universal truth of weight loss that even if you manage to shed some body fat, you'll probably find it's harder to keep it all from coming back. Why does this happen? A new study may have the answer: fat tissue retains a 'memory' of sorts after the cells become obese.

"This is a piece of the puzzle in potentially explaining how changes in adipose tissue (body fat) occur during weight change," Dr Ferdinand von Meyenn, assistant professor at ETH Zürich's Department of Health Sciences and Technology, told *BBC Science Focus*.

Von Meyenn and his team found transcriptional changes (alterations to the way our cells copy and control genetic material) in the cells of people they studied. They compared the sequences of cells within the fat tissue of people who were and weren't living with obesity, before and after a 25-per-cent reduction in their body mass index.

"The genes [we looked at] were so deregulated during obesity, that they didn't return to their normal state, even at transcription level," says von Meyenn. "The body really fights against [weight loss] and wants to return to its original weight. The adipose tissue is programmed to want to regain that weight."

This may not be news that people trying to lose weight want to hear, but von Meyenn shared hopes the findings will help to destigmatise weight fluctuations.

"People who can't maintain their body weight aren't 'weak' people. There really is an underlying molecular mechanism driving gaining the weight back," he said.

Von Meyenn explained that the best strategies to help with global obesity trends are preventative. "Intervention early on is really key because once you've gained weight, it'll be much harder to lose it again," he said. "So, at a societal level, enforcing healthier living measures is quite important."

ILLUSTRATIONS: ADAM GALE

PSYCHOLOGY

Abbreviations make your messages seem less sincere

FYI, the common practice can make it look like you're not fully invested in your correspondence

Not getting many replies to your text messages? A new study suggests it could be down to a common texting habit: abbreviating words.

While most texters use abbreviations in their messages, research carried out at Stanford University, in the US, suggests it could signal that you're not fully invested in the conversation you're having.

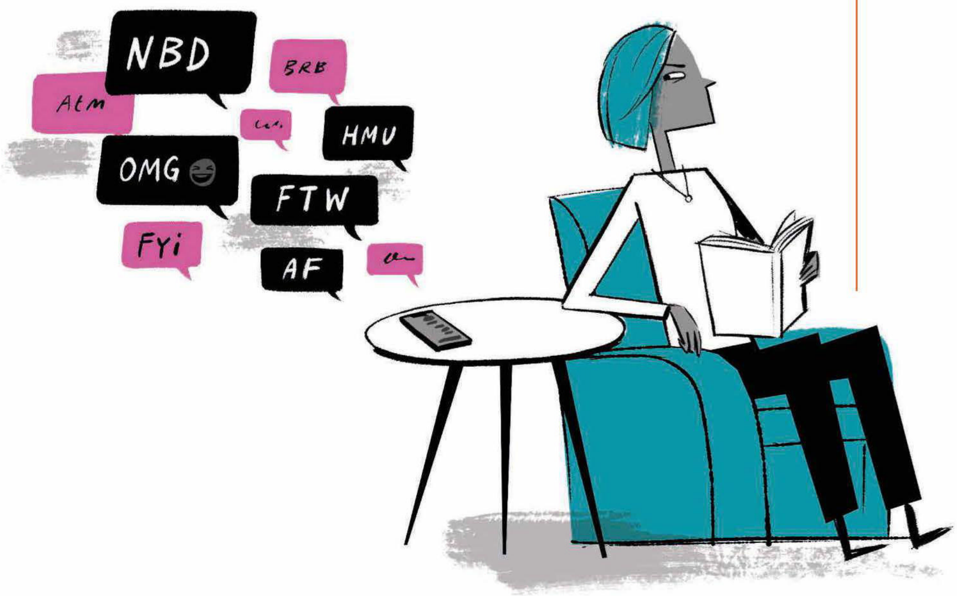
The researchers discovered that people who used abbreviations in their text messages were less likely to receive replies, and the use of them could cut conversations short.

"Our findings are especially relevant when we want to appear more sincere and strengthen social ties, such as at the beginning of a relationship or when we need to make a good impression," said lead researcher David Fang, a doctoral student at Stanford University.

The research, published in the *Journal of Experimental Psychology: General*, analysed conversations from 37 countries and more than 5,300 texters. The conversations, including ones with and without abbreviations, came from messages on dating apps and chatrooms.

Rather than making participants appear laid-back, the findings suggest that not spelling out words in full made a person – whatever their age – appear insincere. Nevertheless, 80 per cent of participants predicted that others wouldn't mind the use of abbreviations – and four per cent wrongly thought it would have a positive impact.

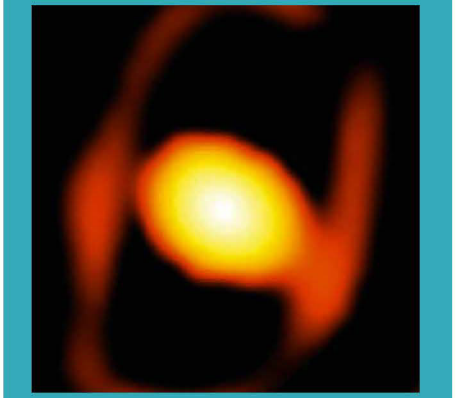
"We thought texters might like abbreviations because it would convey an informal sense of closeness, so we were surprised that abbreviations elicited negative perceptions about people who use them," explained Fang.



SPACE

Star outside our galaxy imaged for first time

Scientists have captured a close-up of WOH G64



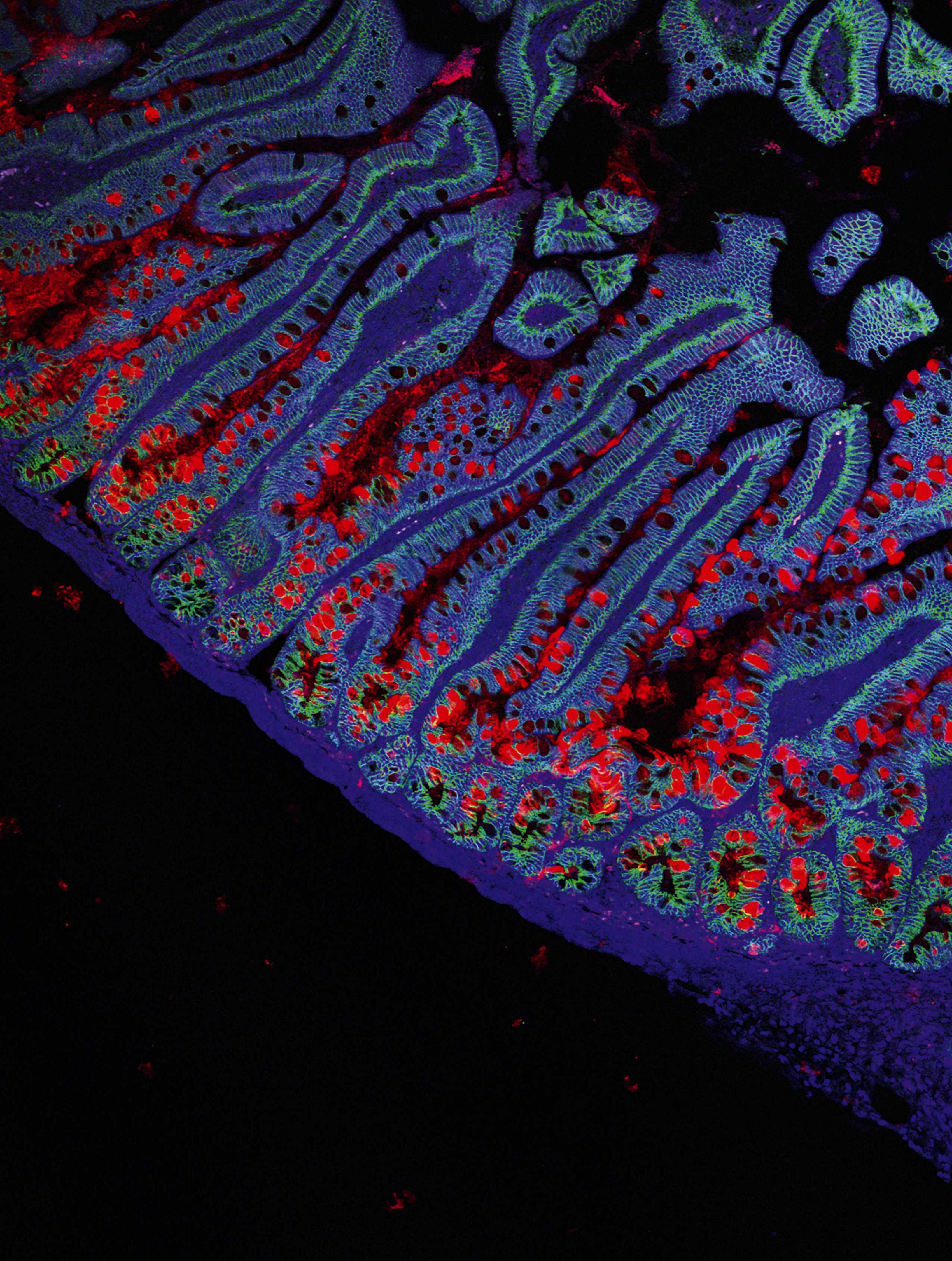
For the first time ever, scientists have captured a zoomed-in image of a star outside the Milky Way. Known as WOH G64, the colossal red supergiant was pictured 160,000 light-years away shedding its outer layers, the prelude to a supernova explosion.

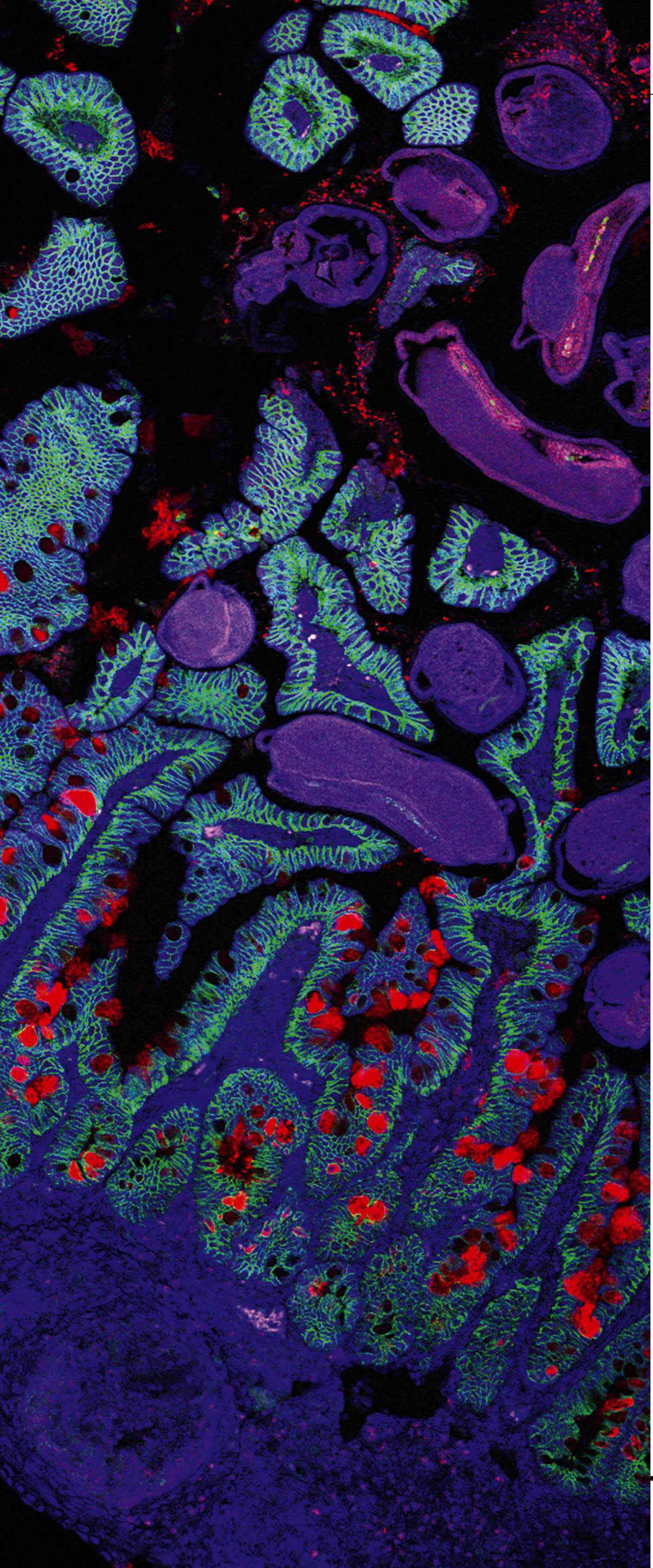
To date, experts have only taken zoomed-in, detailed photos of 25 stars within our galaxy.

"This star is one of the most extreme of its kind and any drastic change may bring it closer to an explosive end," said Dr Jacco van Loon, co-author of the study that reported the observation.

The dying star lies within the Large Magellanic Cloud, a dwarf galaxy that's about one-third the size of the Milky Way.

"Observing a star within our galaxy in such detail would be remarkable, but it's even more extraordinary given that WOH G64 is located beyond the Milky Way," Dr Darren Baskill, physics and astronomy lecturer at the University of Sussex, who wasn't involved in the project, told *BBC Science Focus*.





GRACE BURGIN/NOGA ROGEL/MOSHE BITON/KLARMAN CELL OBSERVATORY/BROAD INSTITUTE

BIOLOGY

Map of 100 million human body cells revealed

Over three dozen new studies mark a significant milestone towards a complete Human Cell Atlas

37 trillion
The number of cells in the human body

100 million
The number of human cells the researchers have mapped so far

10,000
The number of people the cells used to compile the Human Cell Atlas have come from. Researchers hope the final Atlas will include billions of cells

1.6 million
The number of cells needed to create an intricate map of the gut

The image on the left might resemble an estuary system painted in neon colours, but it's actually an extreme close-up of your small intestine. The organ is around 7m (almost 23ft) long and plays a key role in breaking down the food that you eat.

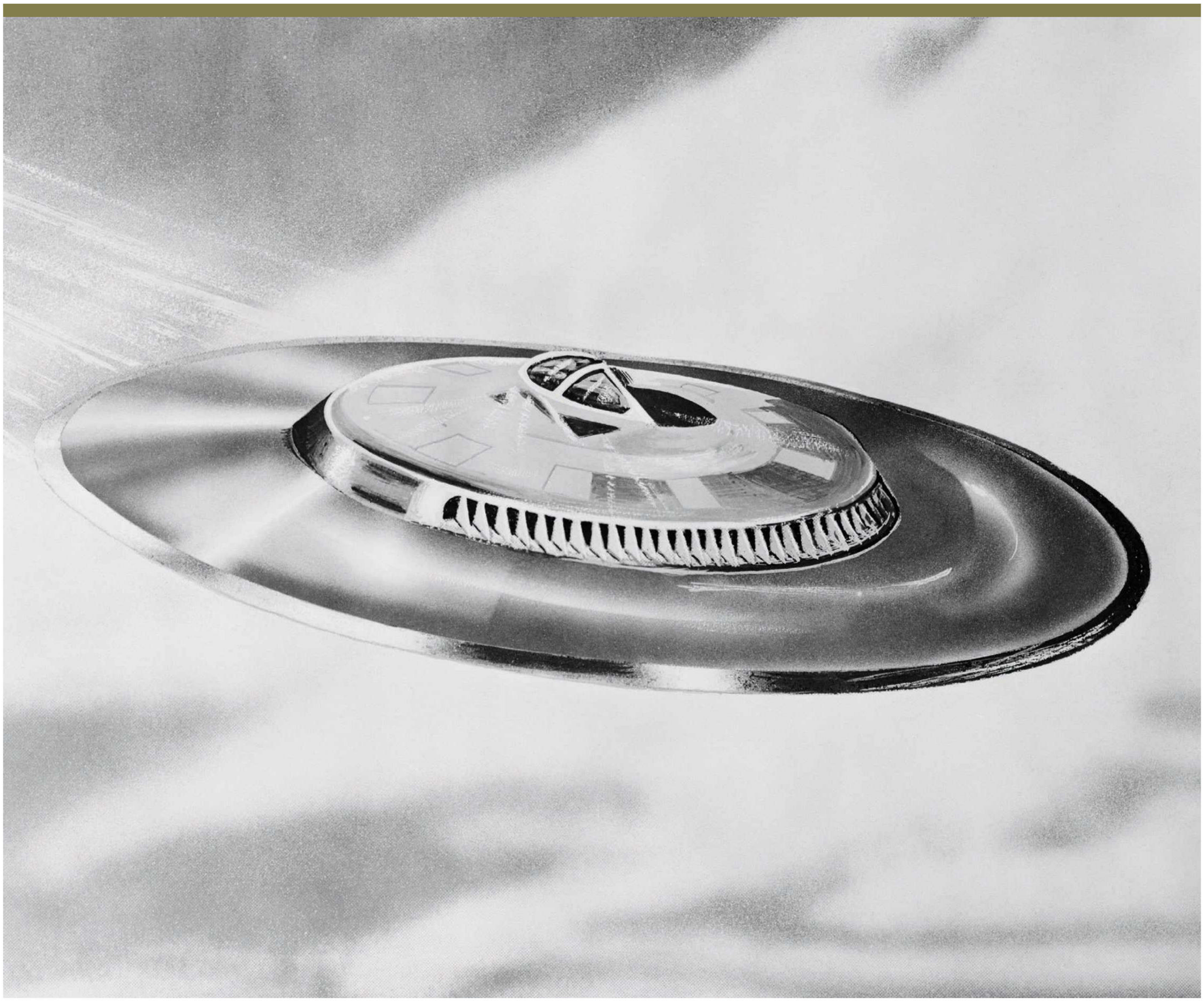
The image is part of a project known as the Human Cell Atlas: a map of the human body on a scale that takes in the tiny cells that make up our organs, and includes information on how they change. It's considered to be the most thorough map of its kind ever made.

New research carried out in the course of completing the Atlas, and published across 40 studies in the *Nature* portfolio, may help to answer significant medical mysteries, such as how bones form, and how arthritis and Crohn's disease develop.

Prof Sarah Teichmann, founding co-chair of the Human Cell Atlas, who also works at the Cambridge Stem Cell Institute, said: "This new level of insight into the specific genes, mechanisms and cell types within tissues, is laying the groundwork for more precise diagnostics, innovative drug discovery and advanced regenerative medicine approaches."

REALITY CHECK

THE SCIENCE BEHIND THE HEADLINES



REVIEW

US Congress is talking about extraterrestrial activity again. Is the truth really out there?

Despite several testimonies, the question remains frustratingly unanswered

BBC

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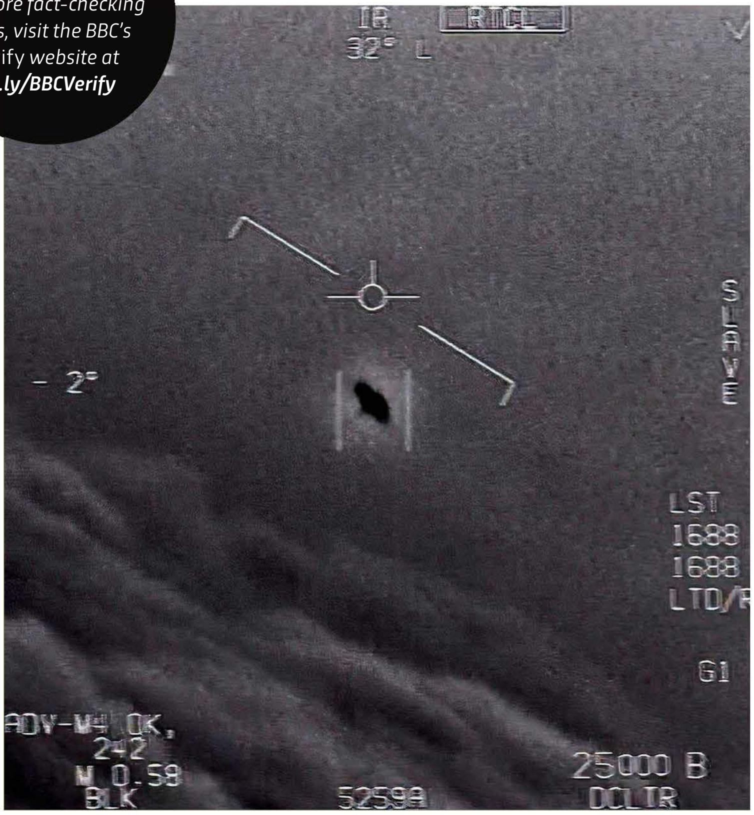

ABOVE An image taken from a video provided by the US Department of Defense in 2015 showing a UAP

LEFT An artist's impression of a disc-shaped aircraft said to be in development for the US Air Force in the 1950s

On 13 November 2024, four witnesses appeared before the Joint Subcommittee on Oversight and Accountability of the US Congress for a session of testimony about so-called 'Unidentified Anomalous Phenomena (UAPs)'. This is the necessary rebrand of the term 'UFO' – people spouting those three letters in the past were hardly seen as credible, or worthy of testifying in front of the US government.

The four witnesses were the former commander of the US Naval Meteorology and Oceanography Command, Rear Admiral Dr Tim Gallaudet; retired director of the Pentagon's former Advanced Aerospace Threat Identification Program, Luis Elizondo; investigative journalist Michael Shellenberger; and former NASA associate administrator Michael Gold.

The four submitted written testimony ahead of the hearing. Shellenberger also filed an allegedly original document from an unnamed whistleblower about a programme called "Immaculate Constellation", an "unacknowledged special access program" for top-level oversight of UAP-related activities.

The document contained an extensive database of high-quality evidence collected over a series of decades, all of which had previously evaded the democratic scrutiny of Congress.

An earlier hearing was held on 26 July 2023, with former US Navy pilots testifying to events like the encounter with the famous "Tic Tac-looking object" and the FLIR (forward-looking infrared) video from the 2004 USS *Nimitz* encounter, as well as the GoFast and Gimbal videos from the 2015 USS Roosevelt incident.

> **"They reported being threatened not to disclose any classified materials"**

Earlier reports of UAP/UFO sightings date back to the 1940s and, according to some, even centuries before that. The reveal of new evidence and previously hidden reports appears to come in waves. Suspicions about government cover-ups have been in the air since the 1947 Roswell incident, but this recent surge in interest regarding government secrecy was triggered in 2017 thanks to a *New York Times* article about the Pentagon's alleged UAP programme.

This caused the US Congress to take bipartisan interest in uncovering the extent to which the US government and intelligence agencies had withheld information about sightings. They committed to provide transparency to the American public.

So far, it seems fair to say that the attempt at transparency has failed abysmally. Witnesses have refused to disclose classified materials that may violate their oaths of confidentiality, and the government's denial of their declassification of materials (or even acknowledgement of the materials' existence) created obstacles that affected the UAP disclosure debate from really taking off.

The hearing of 13 November 2024 was no exception. Chairwoman Nancy Mace started off the hiding game by stating that she wasn't going to "name names". She also said that there had been people trying to influence her not to hold this hearing.

All witnesses, except Gold, repeatedly stressed that they were either not allowed or willing to discuss certain questions in an open session, or not allowed or willing to discuss them full stop (Shellenberger claimed it was to protect his journalistic sources). They also reported that they had been the subject of intimidation and outright threats to not disclose any classified materials.

CLOSE ENCOUNTERS

Gold didn't disclose any confidential information at all, if he even had any. He merely – and correctly – emphasised the need for an independent scientific and academically rigorous investigation of the phenomenon.

That did not, however, stop the witnesses from claiming that they had knowledge of crash retrieval programmes and of encounters with underwater UAPs (unidentified submersible objects). They also implied that staff were being treated for injuries sustained →

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“Why risk revealing classified documents unless you’re 100-per-cent certain that they’re true?”

→ from contact with UAPs, and that humanity was already dealing with non-human intelligence (NHI). Pieces of information that, if true, would fundamentally change our view of our place in the cosmos. This also points towards there being a mountain of classified materials still being withheld.

The witnesses are, to some extent, allowed to talk about facts that would normally qualify as ‘official secrets’, yet they’re forbidden to disclose the classified material that would support their claims. This means we can never really know if what they say is true. A sufficient inkling of doubt always remains around their testimony.

They may all be sincere in their beliefs or have access to pertinent evidence, but it’s this personal redaction that inevitably sets witnesses up for failure – and in the worst cases, ridicule.

In many of the hearings so far, however, they’ve presented nothing more than stories they’ve been told – ‘hearsay evidence’, in legal terms – which legal systems around the world deem to be an inadmissible type of evidence.

This makes it easy for so-called ‘debunkers’ to point out that the evidence is always announced as being disclosed soon, but never is.

BELOW Brigadier General Roger M Ramey identifying metallic fragments found by a farmer near Roswell, New Mexico, as pieces of a weather balloon

by **PROF MICHAEL BOHLANDER**

Michael is the Chair in Global Law and SETI Policy at Durham Law School.

And unfortunately, not all of the witnesses who appeared before Congress on 13 November have a spotless reputation when it comes to due diligence and fact-checking their information.

Elizondo, for example, was recently caught out at a talk presenting a photo that was supposedly taken in Romania in 2022 and obtained from a government contact. He alleged it to be of a giant “mothership”, but it turned out to be a fake.

His response was to congratulate the people who spotted his mistake and to say he was always happy to have false evidence eliminated from the serious UAP narrative.

Be that as it may, former US officials ought to reconsider their blind loyalty to secrecy and examine if there’s any real benefit to obeying their government’s demand for silence. Currently, their unwillingness to disclose information is only further empowering the US government’s quest to obscure the democratic process. If the witnesses’ claims are true, then this knowledge should be shared with the world, not held by one country’s government.

WAR OF THE WORDS

The question of whether we’re alone in the Universe, or even on this planet, is not, by definition, a matter of national security. This short-sighted view currently held by domestic intelligence agencies is not fit to be a guiding policy principle going forward.

Someone someday will inevitably have to take the drastic decision to publish or release the classified materials they have access to, stamping their name on them and risking the consequences. In actuality, the threat of legal consequence would not only add a lot of credibility to the whistleblower’s character, but also reliability to their testimony. Why risk revealing classified documents unless you’re 100-per-cent certain that they’re true?

It’s unlikely that there would be any actual repercussions once the truth got out to the public; “There’s no point in trying to defuse a bomb once it’s gone off,” to steal a line from Jack Ryan in *Clear and Present Danger*.

Until then, the pointless charade of unchecked, hearsay testimony will play out again and again on the floors of Congress. It’s better to ignore the witnesses’ protests that they can’t reveal any real information and actively discourage their spreading of unverifiable allegations, than it is to remain in the permanent limbo of alien gossip and innuendo. Keeping their lips zipped is ultimately doing a massive disservice to whatever truth is behind UAPs.

ANALYSIS

Could your cosmetics be harming your health?

Cosmetic companies are phasing out microplastics and so-called 'forever chemicals' to help protect consumers

The cosmetic industry is big business. In 2023, the European market was worth €96 billion, with the UK being the fourth-biggest consumer, spending €11 billion, after Italy, France and the leader, Germany. More and more of us, both men and women, are routinely using cosmetics and the trend shows no sign of slowing down anytime soon. But what are we actually putting on our hair and skin, and could it potentially cause us harm?

The ingredients used in cosmetics are tightly regulated in the European Union and many other areas. Only approved ingredients can be used and this list is regularly updated based on emerging scientific evidence.

The process for banning an ingredient from cosmetics in Europe is that the European Chemicals Agency (ECHA), which is responsible for the regulation of chemicals, first files an intention to restrict notice. This is followed by a call for evidence, in which any interested person or group submits data and evidence for the safety or otherwise of the chemical in question. This evidence is then evaluated by the various scientific committees. Then a recommendation is made and, finally, a decision is agreed upon by the European Commission. The process can take several years.

As companies are warned when changes in regulations are coming, however, they're able to voluntarily reduce and replace the substances that will be restricted in the future. This was seen, for example, with the plastic microbeads that used to be found in toothpastes and facial scrubs. Companies began phasing them out even before the ban on microbeads came into full effect in 2018, as the industry knew that microbeads would soon be banned, so products containing them were rapidly removed from store shelves.

Plastic is still a major component of many cosmetics, however, especially leave-on ones, designed to remain on the skin for several hours. These products were not covered by the microbeads ban, but are now being phased out over the next seven years as part of the EU restriction on intentionally added microplastics.

There are a number of reasons that microplastics are considered to be potentially harmful to humans – the main one being their small size. We can breathe them in and eat or drink them. They also breakdown very slowly and can thus →

ABOVE Skin is an effective barrier for keeping out unwanted chemicals, but they can still find ways into your body

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→ remain in our bodies for extended periods of time. In most cases they were not designed to be ingested or inhaled, and so they typically contain additives such as flame retardants or plasticisers, which are toxic to humans.

The skin is a very effective barrier at keeping things out and thus you might think that microplastics in cosmetics aren't a major source of internalisation. There are still potential pathways of uptake for microplastics via hair follicles or damaged skin, however.

COSMETICS ARE FOREVER

Another group of chemicals that is receiving a lot of attention are so-called 'forever chemicals' – the family of more than 10,000 multiply fluorinated compounds with three or more carbon atoms, collectively called poly- and polyfluoroalkyl substances (PFAS).

The extreme persistence of these synthetic chemicals in the environment means that even ones that were banned over a decade ago are still being detected in human breast milk and blood. 36 PFASs (polymeric and non-polymeric) have been identified as being used in cosmetic products. They're intentionally added to some products for a number of reasons, for example, as a binder to keep powders together and as a skin conditioner to aid moisture retention.

PFASs aren't a common ingredient in cosmetic products, however, at least not in the UK and EU, where ECHA's cosmetic database indicates that across all categories of cosmetics products, PFAS-containing products make up less than 10 per cent of the products on the market.

In the UK, a 2020 survey by the Cosmetic, Toiletry and Perfumery Association, which represents 85 per cent of the UK cosmetics market, found that only 1.5 per cent of member companies reported use of PFASs. Even then, only nine PFAS ingredients were reported as being used and they're being phased out rapidly.

But there are potential routes for PFAS to get into products unintentionally, for example as a degradation product or an impurity that's not referenced on the ingredients list.

ABOVE The use of microbeads in rinse-off cosmetics was banned in the EU in 2018

RIGHT The phasing out of PFAS chemicals in recent years means fewer cosmetic products intentionally contain them today

> "There are still potential pathways of uptake for microplastics via hair follicles and damaged skin"

ALAMY, GETTY IMAGES

The vast number of different PFAS molecules makes generalisations about their human health effects challenging. But there are indications that the long-chain substances such as PFOS (perfluorooctanesulfonic acid) and PFOA (perfluorooctanoic acid) can cause reproductive and developmental issues, as well as liver and kidney immunological effects in laboratory animals. Furthermore, both chemicals have caused tumours in animal studies.

Another recent study using model skin also demonstrated for the first time that dermal exposure to PFASs can allow them to pass through the skin barrier, and that dermal exposure could be a significant source of exposure to shorter-chain PFAS.

GETTING CLEAN

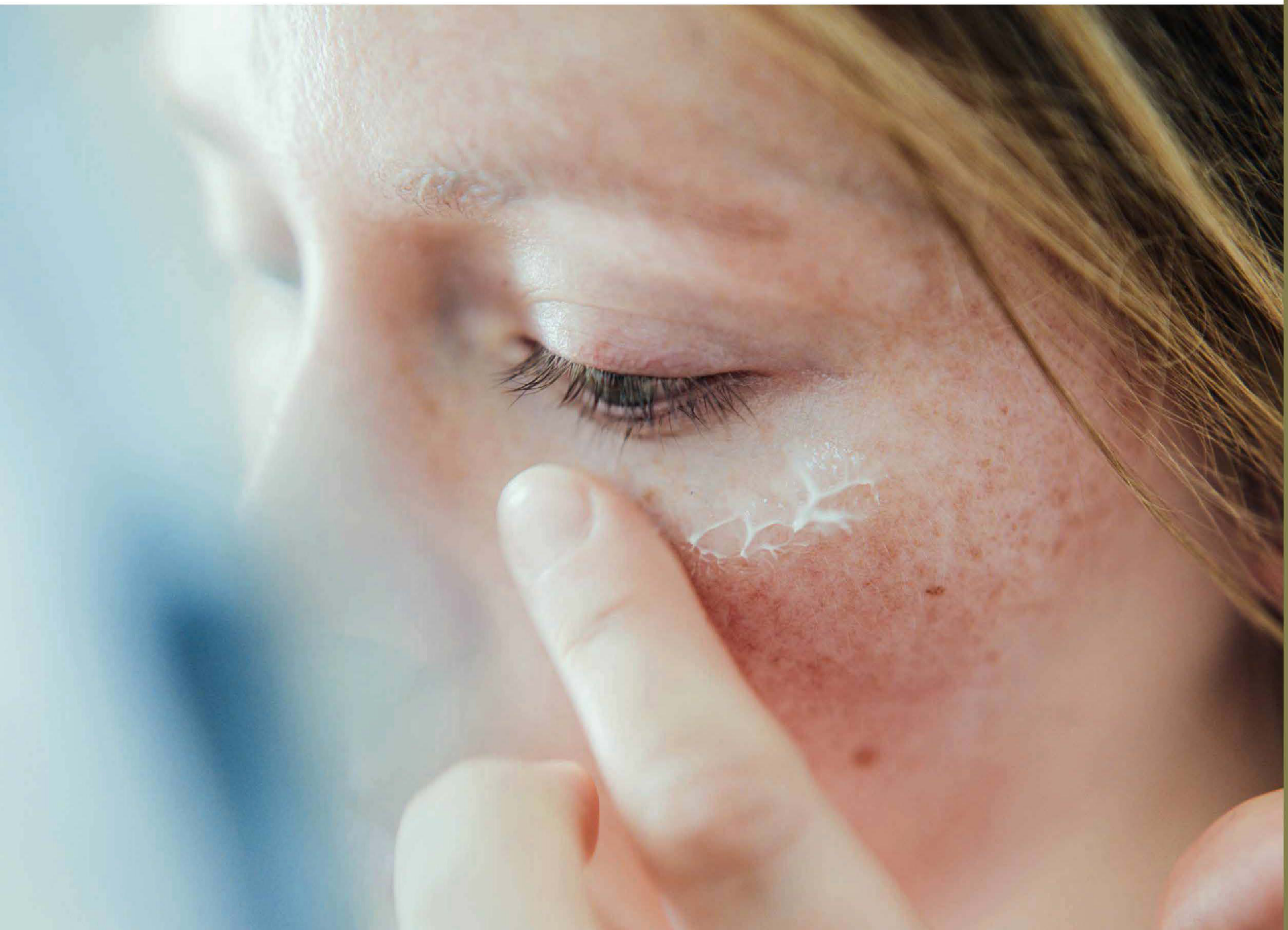
Driven by the persistence of PFASs and their widespread use, in early 2024, ECHA announced its intention to restrict the production, use and placing on the market (including import) of at least 10,000 PFASs, including those used in cosmetics.

Based on the low amount of cosmetics that contain PFASs, and the fact that the cosmetics industry has been actively phasing out their use for the past five years, the restriction is not expected to cause much of a challenge for the industry. Approximately 47 products from large companies and 197 products from smaller companies might need reformulation. In comparison, tens of thousands of product reformulations may be required in the case of the restriction of intentionally added microplastics.

So, should you be concerned? The regulatory process is working hard to respond to new information and to phase-out the use of chemicals of concern in cosmetics. Europe and the UK also have robust regulations regarding the labelling of products, and cosmetics and other products must list their ingredients in order of quantity, starting from the ones present in the highest amounts.

While the chemical names may be hard for most consumers to follow, the CoSMILE database (cosmileeurope.eu) provides clear information about specific ingredients that you can look up. There's also a range of smartphone apps that can scan ingredient lists and highlight any potential health hazards, including a lack of available data (which is classified as a hazard). Consumers can use these to better inform their purchases. SF

PROF ISEULT LYNCH
Iseult is a professor of environmental nanomaterials at the University of Birmingham.



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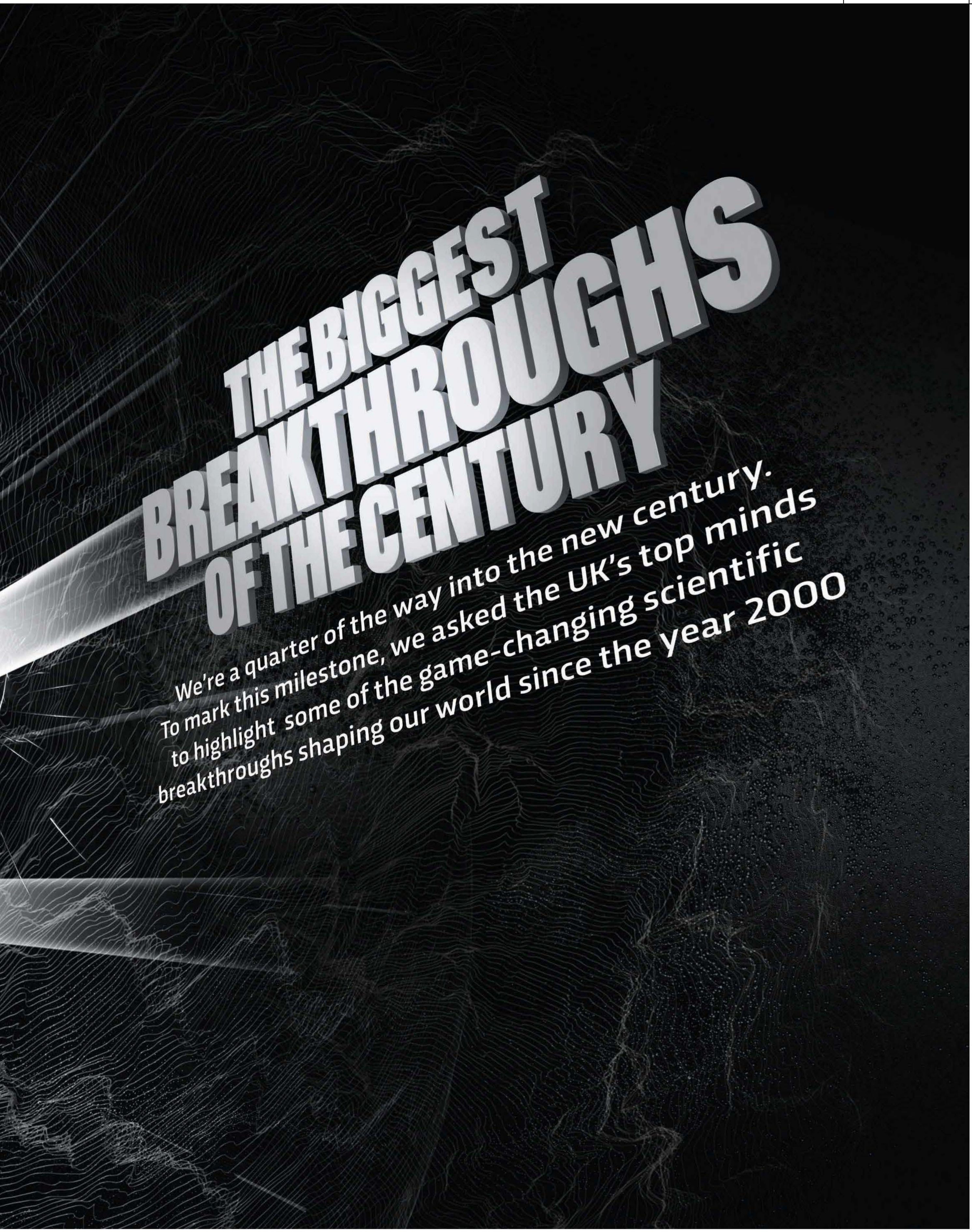


THE BIGGEST BREAKTHROUGHS OF THE CENTURY

We're a quarter of the way into the new century. To mark this milestone, we asked the UK's top minds to highlight some of the game-changing scientific breakthroughs shaping our world since the year 2000

TISSUE ENGINEERING

➥ Sir Mark Miodownik

Professor of Materials & Society, UCL

Author of *It's a Gas: The Magnificent and Elusive Elements that Expand Our World*

Going to the dentist and having a synthetic resin filling is fine, but it's not as good as a real tooth. But what if we could grow real teeth in the lab from a person's own stem cells and implant them back into their mouth?

This sounds like science fiction, but tissue engineering is a breakthrough technology that's already being used to grow human tissue, through 'scaffold technology'. Scaffolds are porous materials that support stem cells as they divide and grow into new tissues. Artificial ears, trachea (windpipes) and bone have been grown this way and successfully implanted into human patients. Because the implanted tissues are grown from a patient's own cells, there are no problems with immune rejection.

Artificial kidneys, knee cartilage and even hearts are also being grown this way, although these are still confined to lab experiments. No one can yet put a limit on this new technology, but the successful regrowing of teeth is on the horizon.

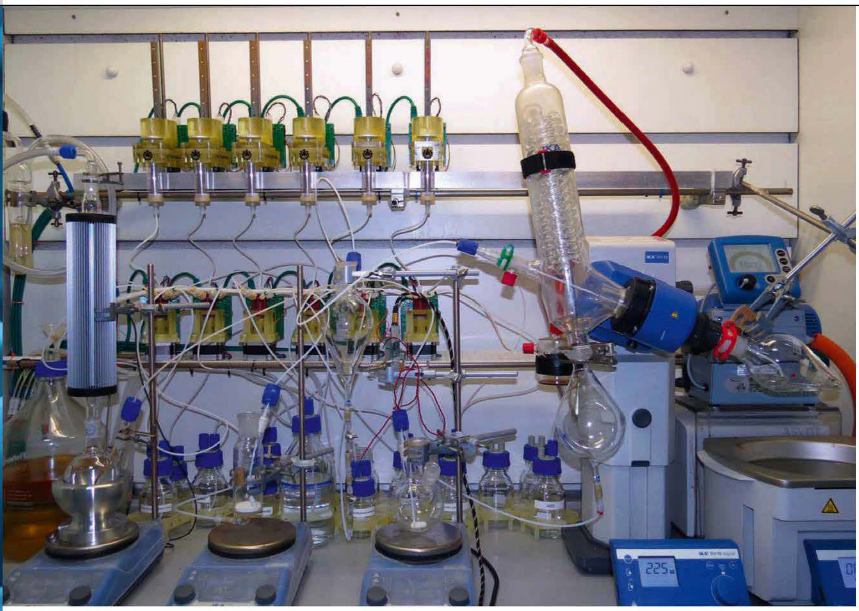
...BUT ALSO SELF-REPAIRING MATERIALS

A modern smartphone contains half the elements in the periodic table and yet only has a lifespan of two to three years, on average. To save the massive amounts of energy we're wasting on continually producing (and even recycling) phones and everything else that fills our lives, we need to find a new way of making products that last longer.

This is where the breakthrough technology of self-repairing materials comes in. Imagine a smartphone that can repair itself overnight when you plug it in.

Many different types of this technology are already on the market. Self-healing paints have room temperature fluidity, allowing them to flow back into cracks and fill the fissure when they form. Self-repairing concrete for bridges and self-repairing asphalt for roads have already been deployed this century. Self-repairing electronics are coming to help us build a sustainable future.

An illustration of artificial biological tissue growing on a hyaluronic scaffold



UNIVERSAL PROGRAMMABLE CHEMICAL ROBOTS

➥ Prof Lee Cronin

Regius Professor of Chemistry, University of Glasgow

ABOVE A chemputer robot in Prof Cronin's chemistry lab in Glasgow

SCIENCE PHOTO LIBRARY, CRONIN GROUP/SCHOOL OF CHEMISTRY/GLASGOW UNIVERSITY

What if any chemical reaction could be performed through code? This is what has become possible with the ground-breaking advancement known as chemical computation, or 'chemputation'.

Chemputation combines automation, computation and modular hardware to transform chemical synthesis into a programmable, universal process.

At its core is the 'chemputer' – a revolutionary platform capable of executing any feasible chemical synthesis. It uses a concept known as 'chempiling', which translates chemical synthesis pathways into executable hardware configurations – basically acting as a chemical Turing machine. This process digitalises chemistry, increasing efficiency, accelerating research and reducing the risk of human error.

The integration of artificial intelligence into automated synthesis takes this innovation further, enhancing decision-making at every step of the process, from molecule design to reaction execution. Because of this, chemputation is unlocking immense potential in drug discovery, material science and more.

BBC SOUNDS

Prof Lee Cronin appears in series 3 of *Brainwaves*. Listen now

THE SCIENCE OF DREAMING

➥ Prof Richard Wiseman

Professor of the Public Understanding of Psychology, University of Hertfordshire

Author of *Magic Your Mind Happy*

Until the turn of the last century, psychologists often argued that dreaming was a meaningless experience best confined to the fringes of science. But the 21st century has witnessed a surge of scientific interest in our nocturnal adventures and produced a steady stream of articles exploring the psychology of dreaming.

Some of this work has explored how dreaming can help people process negative emotions and prepare them for challenging events in the real world. Another strand of research has explored the link between dreams and creativity, and has shown that our dreaming minds often come up with new and innovative solutions to pressing problems.

There's also work that has looked at the social side of dreaming, with psychologists arguing that discussing a dream with others is an effective way of forming and maintaining caring relationships. Other scientists have taken a different approach and developed techniques that allow them to communicate with people experiencing a lucid dream.

Finally, there's dream engineering, wherein researchers use smells, sounds and suggestions to manipulate our dreaming minds.

For years, trying to convince scientists to take dreams seriously was a nightmare. Now the tide has turned and we're starting to uncover the many ways in which dreaming makes a vital contribution to our waking lives.

BBC SOUNDS

Listen to Prof Wiseman's episode of *The Life Scientific* on BBC Sounds now

GLOBAL HEATING

➡ Prof Bill McGuire

Professor Emeritus of Geophysical & Climate Hazards, UCL

Author of *Hothouse Earth: An Inhabitant's Guide*

An air tanker drops fire retardant on a house in California during one of 2024's wildfires

BBC SOUNDS
Listen to *Rethink Climate* on BBC Sounds

Only by looking into the past can we get an inkling of the seriousness of today's climate predicament. The terrifying reality is that the global average temperature rise, which is now teetering on the edge of the 1.5°C dangerous climate breakdown guardrail, is occurring 50 times faster than when the world warmed after the Ice Age. That was 56 million years ago, during the Palaeocene-Eocene Thermal Maximum (PETM).

The episode of rapid heating saw dead, oxygen-depleted oceans and sea levels 50m higher than they are now. And the global temperature today is ramping-up at least ten times faster than during the PETM.

We're in the middle of a unique climate experiment, continually pumping out 40 billion tonnes of carbon dioxide every year, and hoping that it'll be fine.
I can tell you now, it won't be.

...BUT ALSO ATTRIBUTION ANALYSIS

In a nutshell, attribution analysis seeks to determine the extent to which global heating has influenced a particular extreme weather event, such as increasing its intensity or raising its likelihood.

It involves running two computer simulations. One assumes today's artificially heated climate, the other assumes a pre-industrial climate with all the human influences removed. Comparison reveals whether global heating had an effect and, if so, what it was.

The first-ever attribution analysis determined that the 2003 European heatwave (which claimed 70,000 lives and saw temperatures breach the 37°C/98°F mark for the first time in the UK) was made twice as likely by global heating.

Attribution analysis sheds light on the growing impact global heating is having on our weather patterns, while also loudly undermining the climate deniers – a win all round.

MRNA VACCINES

➡ Dr Jeremy Rossman

Honorary Senior Lecturer in Virology, University of Kent

The use of mRNA for various medical applications has been in development for decades. It wasn't until the COVID-19 pandemic that the impact of the technology was first felt, however.

mRNA vaccines allow for the development of vaccines far more quickly than was previously possible – two months for COVID-19 compared to the previous record of four years. It's estimated that the COVID-19 mRNA vaccines saved nearly 20 million lives in their first year of use. In the coming years, we'll likely have a range of new mRNA vaccines for other viruses that change regularly, like the flu, as well as for viruses that haven't responded well to previous vaccine technology, like HIV.

...BUT ALSO THE HUMAN GENOME PROJECT

In 1990, scientists began to sequence the human genome. It took until 2022 to produce a complete sequence. This achievement has profoundly changed biomedical science, allowing for research and technology that wouldn't be possible otherwise, like using CRISPR to modify genetic diseases.

We're just starting to feel the impact of this achievement on medical practice. By knowing our genome, it's possible to find changes in genes that are associated with, or even cause, various diseases. This increases our understanding of those diseases, as well as our ability to diagnose and treat them.

GETTY IMAGES, JOE PETRIK/UNIVERSITY OF WATERLOO

SOLVING THE 'EINSTEIN' PROBLEM

➥ Sir David Spiegelhalter

Emeritus Professor of Statistics, University of Cambridge

BBC SOUNDS
Listen to *More or Less: Behind the Stats* on BBC Sounds

I believe the most important mathematical breakthrough this century is the solution to the long-standing 'einstein' (one-stone) problem. The einstein problem asks whether there is a shape that can tile an infinitely large horizontal surface so that the pattern never repeats.

Brilliant minds had searched for decades for such shapes. Then in 2022, David Smith, a retired print technician and amateur maths enthusiast, began working with software and cardboard cut-outs at his home in Bridlington, Yorkshire. Smith had worked for years on tiling patterns and had a strong intuition his shape, nicknamed the 'hat', would both tile the surface and never repeat.

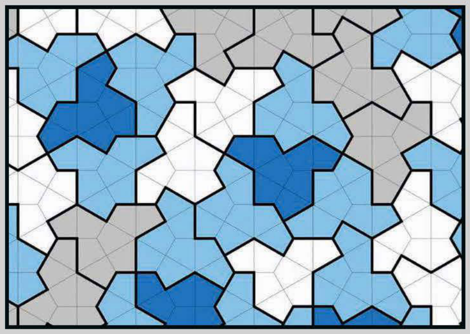
He didn't have the mathematical tools to prove his hunch, however, so he turned to the community of tiling enthusiasts and got help from Prof Craig Kaplan at the University of Waterloo, Canada; Prof Chaim Goodman-Strauss from the University of Arkansas; and software engineer Dr Joseph Myers from Cambridge.

Together they came up with computer-based and analytic proofs for a whole family of shapes, and their preprint study was greeted with international acclaim in March 2023 – even though the 'hat' occasionally needed to be flipped over to successfully tile the plane.

But no sooner had the preprint of their work been released, than David came up with the 'spectre' – a chiral aperiodic monotile, which didn't need flipping. Even more impressive, the 'spectre' was a member of a larger class of such tiles that allows the straight edges to be wavy. Again, his colleagues proved the truth of his intuition. This was a beautiful achievement, led by an extraordinary mathematical hobbyist.

RIGHT A tiling of 'hats' – this tiling can continue forever and there will never be a repeat in the pattern

BELOW Prof Craig Kaplan was one of the people who helped David Smith prove that his hat and spectre shapes solved the einstein problem

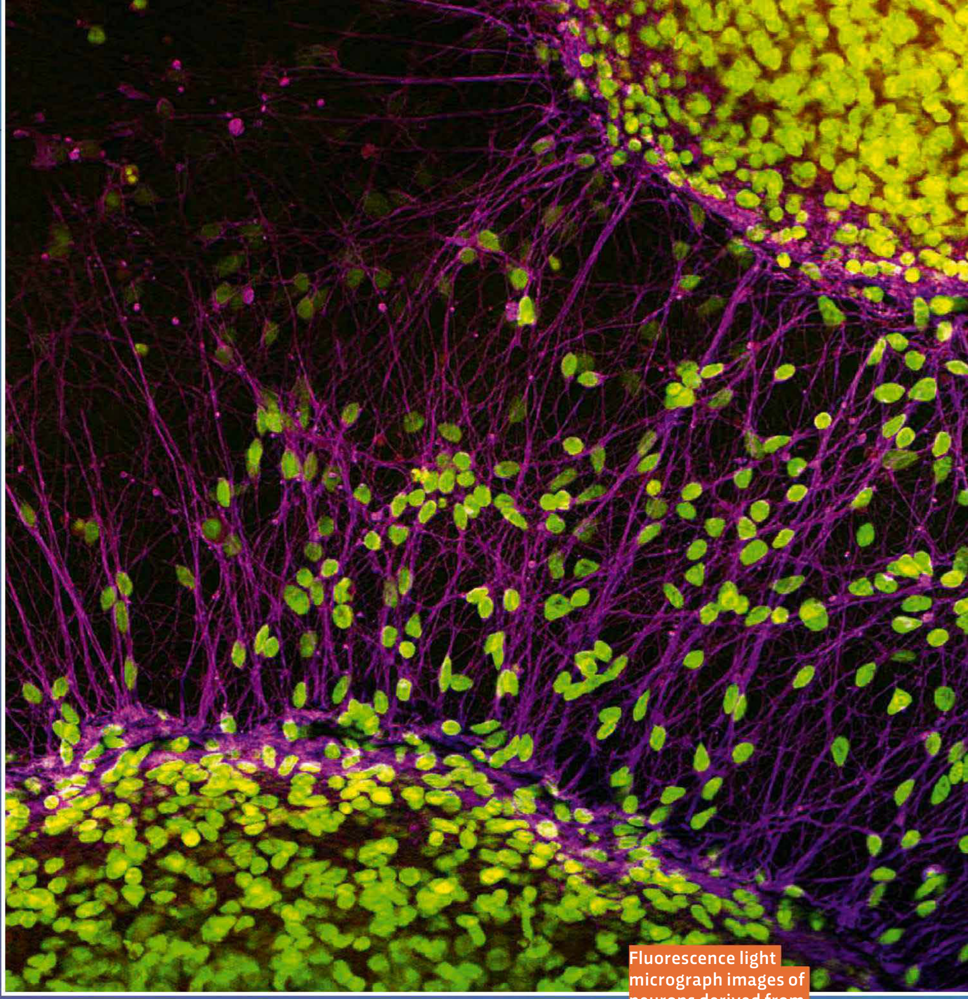


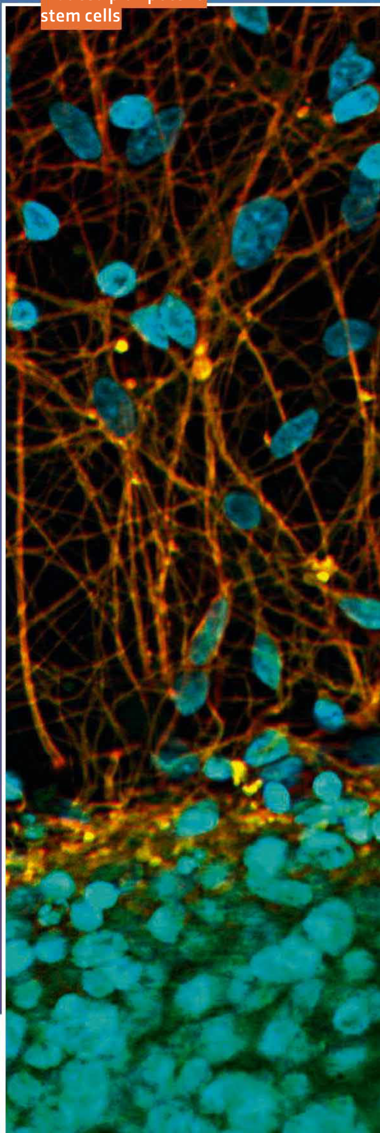
A NEW TYPE OF STEM CELL

➥ Dr Helen Pilcher

Author, speaker and science communication consultant

Author of *Life Changing: How Humans are Shaping the Course of Evolution*





Fluorescence light micrograph images of neurons derived from induced pluripotent stem cells

Before 2006, if researchers wanted to work with human embryonic stem cells, they had to work with human embryos. This was ethically charged territory – the embryos were leftovers from fertility treatments and were destroyed in the process.

Then Prof Shinya Yamanaka from Kyoto University devised a way to make embryonic stem cells without using embryos. By adding a handful of genes into cultured skin cells and nurturing them with certain nutrients, adult cells could be reprogrammed to become 'induced pluripotent stem (iPS) cells.' 'Pluripotent' means that these lab-made stem cells can turn – or 'differentiate' – into many other types of cells, including heart cells and neurons. Now researchers can take cells from an adult animal, turn them into iPS cells and then turn them into the specialised cells of their choice.

iPS cells are now routinely used to help test new drugs and therapies, but perhaps their most exciting use is in the field of regenerative medicine. Imagine a patient with heart disease. Now imagine taking some of their skin cells and using iPS technology to create a pool of healthy heart cells. The replacement tissue could then be transplanted into the patient's heart to repair it, and because the cells are the patient's own, there would be no danger of the tissue being rejected. The same method could be applied to other conditions such as Alzheimer's disease and kidney failure, raising the prospect of cures for currently incurable diseases.

Such brilliant, versatile cells… It's no wonder that Yamanaka received a Nobel Prize in 2012 for his work in their discovery.

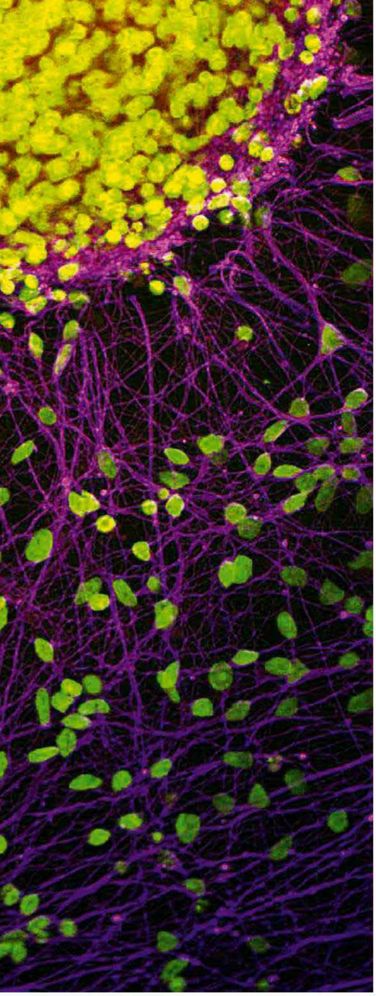
…BUT ALSO THE CURE FOR HIV

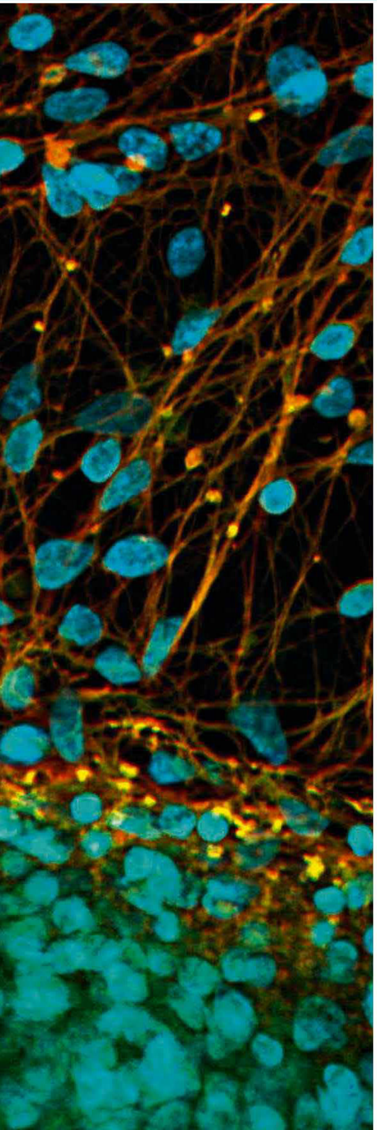
There was a time when HIV was a death sentence. Then anti-retroviral drugs came along and prospects improved. More and more people became able to live with the disease, but a cure still seemed like a distant dream.

Then in 2007, an HIV-positive man called Timothy Ray Brown received a bone marrow transplant for his leukaemia. Chemotherapy had failed and Brown was running out of options. His doctor, Dr Gero Hütter, thought that the treatment might be able to cure his cancer, but he also realised that if he could find a donor who was genetically resistant to HIV, there was a chance that the same treatment might also cure his HIV.

Some people are naturally HIV-resistant. They carry a mutation in a gene called CCR5, which codes for a receptor protein that HIV uses to enter host cells. After scouring the register, Hütter found a donor who not only matched Brown's immune profile, but also carried two copies of the mutated gene. The transplant went ahead and a few years later, researchers could find no trace of HIV in Brown's body. Brown came off his anti-retroviral meds and went on to live the rest of his life HIV-free. He was the first person to be cured of HIV.

Since then, at least six more people with cancer have been cured of HIV using bone marrow transplants. The treatment, however, is brutal, with risks so great that it's unlikely ever to become a routine procedure, but it has taught researchers a great deal about HIV and given hope to the world that a cure for HIV will, one day, be possible.





TRANSFORMERS AND LARGE LANGUAGE MODELS

BBC SOUNDS
Listen to Prof Wooldridge's episode of *The Life Scientific* on BBC Sounds now

➡ **Prof Michael Wooldridge**
Ashall Professor of the Foundations of Artificial Intelligence, University of Oxford

Artificial Intelligence (AI) has been in the news for more than a decade, largely because one key AI technology – neural networks – finally started to work at scale. The new AI era was heralded by the advent of 'deep learning' around 2005, driven by cheap computer power and plentiful data for 'training' neural nets. The field exploded and we began to see a host of impressive applications. AI hit the headlines.

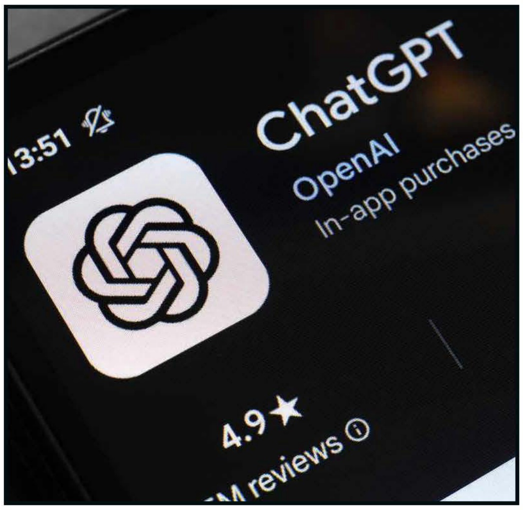
And then, something unexpected happened.

In 2017, a Google team published a scientific paper describing a new architecture for organising neural nets – the so-called 'transformer architecture.' The transformer architecture is a neural network architecture for token prediction: taking as input a sequence of tokens (words) and then predicting the next token (word) to appear.

They're trained by feeding them ordinary human text, and given a 'prompt' (for example: 'a summary of Winston Churchill's life'). They'll then try to predict the word most likely to appear next. They do this one word at a time, but the process can be repeated over and over.

It wasn't obvious in 2017 that transformers would be so… transformative. To realise their full power, you had to be prepared to build them on an unprecedented scale, throw mind-boggling quantities of training data at them and train them with AI supercomputers running for months. Google didn't make that bet; it was a little-known organisation called OpenAI, supported by Microsoft. And it paid off, spectacularly.

The first real hint that we were entering a new era was the release of GPT-3 in June 2020. Those with access to OpenAI's new program seemed genuinely startled by how capable it was. Just as remarkable for AI researchers was its emergent capabilities: the ability to do things that it wasn't designed to do. Questions, like the famous Turing Test, which had been of strictly philosophical interest previously, suddenly became practical experimental questions.



The unprecedented success of Large Language Models (LLMs) like ChatGPT (above) took Silicon Valley by surprise and now the world's richest companies are pivoting to try to embed this remarkable new technology everywhere, in the hope that they'll find the killer application.

For all their success, LLMs aren't the end of the road for AI; the dream of a helpful household robot that can clear your dinner table and load the dishwasher still seems frustratingly distant. But the technology is astonishing nonetheless. We're living at a remarkable time in technological history: our history will be divided into pre-GPT and post-GPT.

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HPV VACCINE

➥ Dr Michelle Griffin

Director of MFG Health Consulting, clinical leader in the NHS and the World Health Organization

At the turn of the century, scientists knew that cervical cancer was caused by Human Papillomavirus (HPV). Of over 200 known HPV strains, two high-risk types – 16 and 18 – are responsible for over 70 per cent of cervical cancer cases. While the UK's cervical screening programme, launched in the 1960s, successfully reduced cervical cancer rates, a huge shift came with the introduction of the HPV vaccine.

The vaccine became part of the UK's national programme in 2008. Today, it's licensed in over 100 countries and offered to both girls and boys to prevent HPV-related diseases, including multiple cancers and genital warts.

In the 15 years since its introduction, the vaccine has provided excellent protection against HPV and has delivered remarkable results – an estimated 90-per-cent reduction in cervical cancer rates among women aged 20–30.

The next frontier is achieving the elimination of cervical cancer – something once thought achievable only for infectious diseases – through widespread HPV vaccination and robust screening programmes.

...BUT ALSO DIGITAL CONTRACEPTION

Non-hormonal digital contraception has revolutionised family planning by combining data-driven insights and user-friendly technology. Apps like Natural Cycles and Clue empower women to track their menstrual cycles and use the data to prevent or achieve pregnancy, offering a convenient and accessible alternative to traditional contraceptives.

These apps utilise algorithms that analyse patterns in body temperature, ovulation cycles and other physiological markers, providing users with real-time predictions of the fertility window in their cycle.

This innovation marks a turning point in women's health. In 2018, Natural Cycles became the first digital contraceptive to achieve US Food and Drug Administration (FDA) regulation, elevating the app to a regulated medical intervention. Natural Cycles reports that the algorithm behind its app has a 93-per-cent success rate, the same as the contraceptive pill.

DARK MATTER

➥ Prof Catherine Heymans

BBC SOUNDS
Listen to Prof Heymans' episode of *Brainwaves* on BBC Sounds

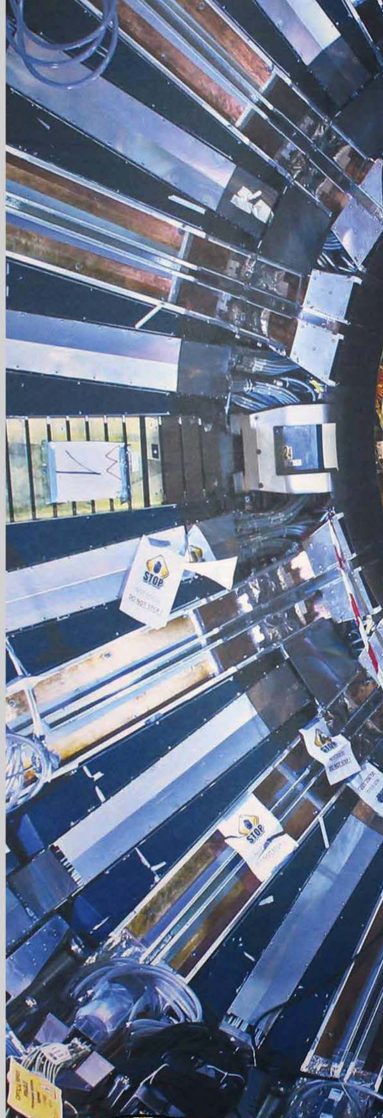
Professor of Astrophysics at the Royal Observatory, University of Edinburgh
Author of *The Dark Universe*

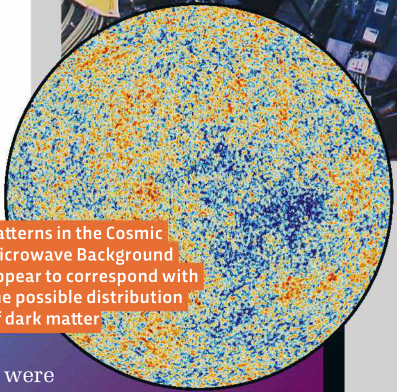
The majority of the Universe is unseen, composed of two entities called dark matter and dark energy, and physics is currently unable to explain the origin of either.

Over the last 25 years, evidence for the existence of dark matter has become more compelling. Using gravitational effects to deduce where and how much of it there is, we've created maps that reveal a pervasive and invisible web. The patterns seen in these maps, in the cosmic microwave background and in the distribution of galaxies, almost match our expectations for a dark Universe.

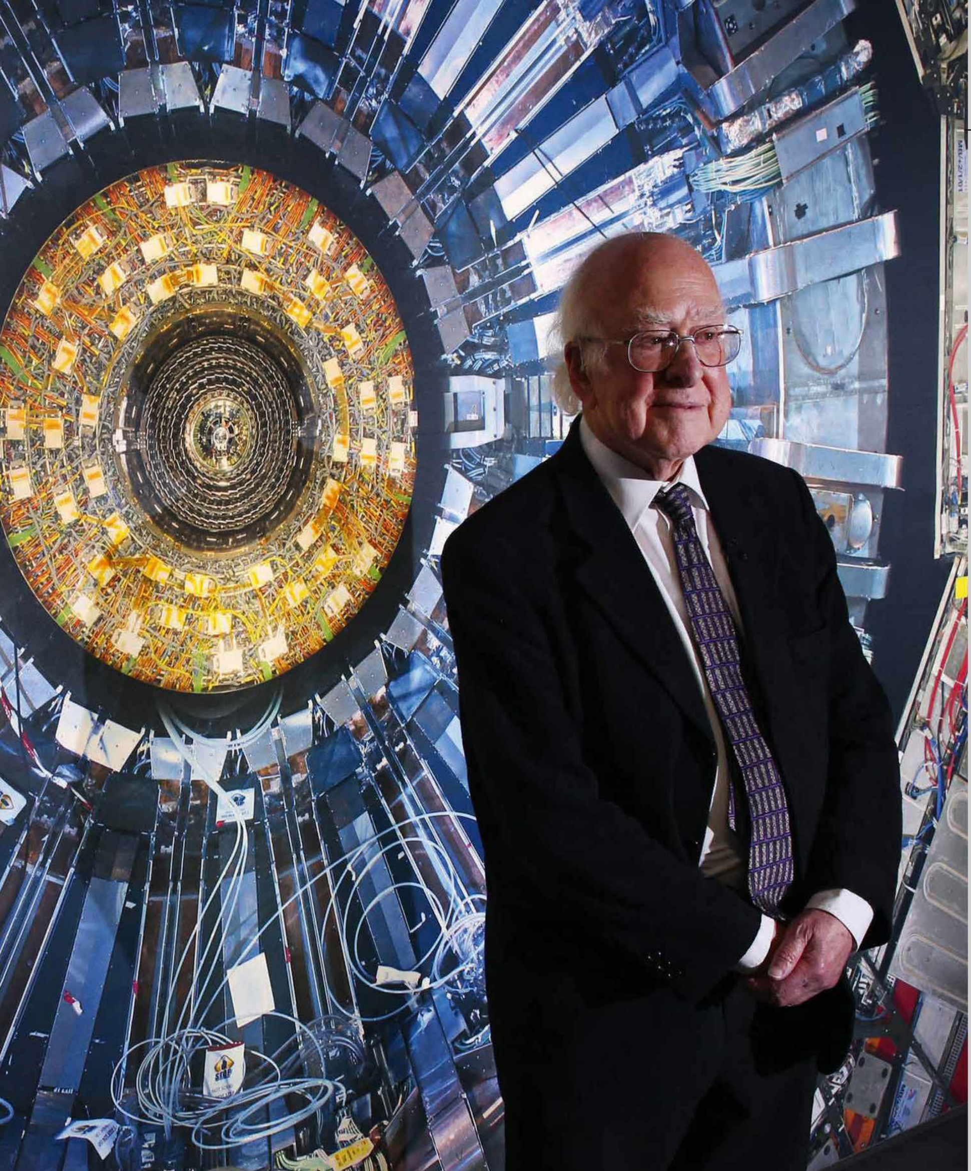
But while 25 years of looking up has increased astronomers' confidence, experimentation tells a different story. After CERN's 2012 detection of the Higgs boson, there were high hopes that the theoretical 'lightest supersymmetric particle' and favourite candidate for dark matter, would be discovered next.

Sadly, the elusive dark matter particle has yet to be found. The lack of detection means that we know what it's not, even if we don't yet know what it *is*. Scientists are working to build the most advanced detector yet, potentially in the UK. Combined with upgrades at CERN and upcoming observations from the Euclid telescope and Vera Rubin Observatory, the hope is very much alive that it won't be another 25 years before we understand the dark matter side of the Universe.





Patterns in the Cosmic Microwave Background appear to correspond with the possible distribution of dark matter



LEFT Prof Peter Higgs, in front of a picture of the Large Hadron Collider

THE HIGGS BOSON PARTICLE

➥ Prof Jim Al-Khalili

Professor Emeritus in Physics, University of Surrey

GETTY IMAGES, ESA/PLANCK

If we were to compare the most important discoveries in physics in the first quarter of the 21st century with those of the same period in the 20th, we might feel quite disheartened by the recent paucity of fundamental advances. Maybe this is because we have largely uncovered the basic laws of the Universe.

It's certainly hard to deny that those first two or three decades of the previous century were a golden age of physics, from the quantum revolution to Einstein's two theories of relativity, to the structure of the atom with Ernest Rutherford.

But the theories and experimental discoveries over the past hundred years have still been remarkable, leading to deep insight into the fundamental building blocks of matter, potentially getting us closer to completing the jigsaw puzzle of reality. One piece of the puzzle that had been missing ever since it was first proposed in the 1960s by Prof Peter Higgs (and others), was the Higgs boson. The particle was proposed as a manifestation of the Higgs field and the Higgs mechanism, explaining how elementary particles acquire mass.

Then, on 4 July 2012, experimental teams working with two giant particle detectors, ATLAS and CMS, at the Large Hadron Collider at CERN, announced they had finally observed the Higgs. It was a landmark achievement in particle physics and a testament to technological innovation in 'big science', international collaboration and the human pursuit of knowledge. It commanded global attention and captivated the wider public.

One might, of course, argue that the discovery of the Higgs wasn't as profound as, say, the accelerating expansion of the Universe in 1998 (which therefore just misses out on this list), because physicists *expected* to find the Higgs. But it confirmed a critical component of the Standard Model of particle physics.

The Standard Model is an amalgamation of two separate quantum theories – the electroweak theory and quantum chromodynamics – which together describe the properties of all the known elementary particles and the forces acting between them. Yet the Standard Model can't be the final word because it doesn't include gravity, doesn't explain dark matter or dark energy, or where all the antimatter that should have been created at the Big Bang has gone.

Fifteen months after the discovery of the Higgs, in October 2013, the Physics Nobel Prize was awarded jointly to Prof François Englert and Prof Peter Higgs, "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles..." It was awarded not for the experimental confirmation of the Higgs' existence, but for the original theoretical prediction half a century earlier.

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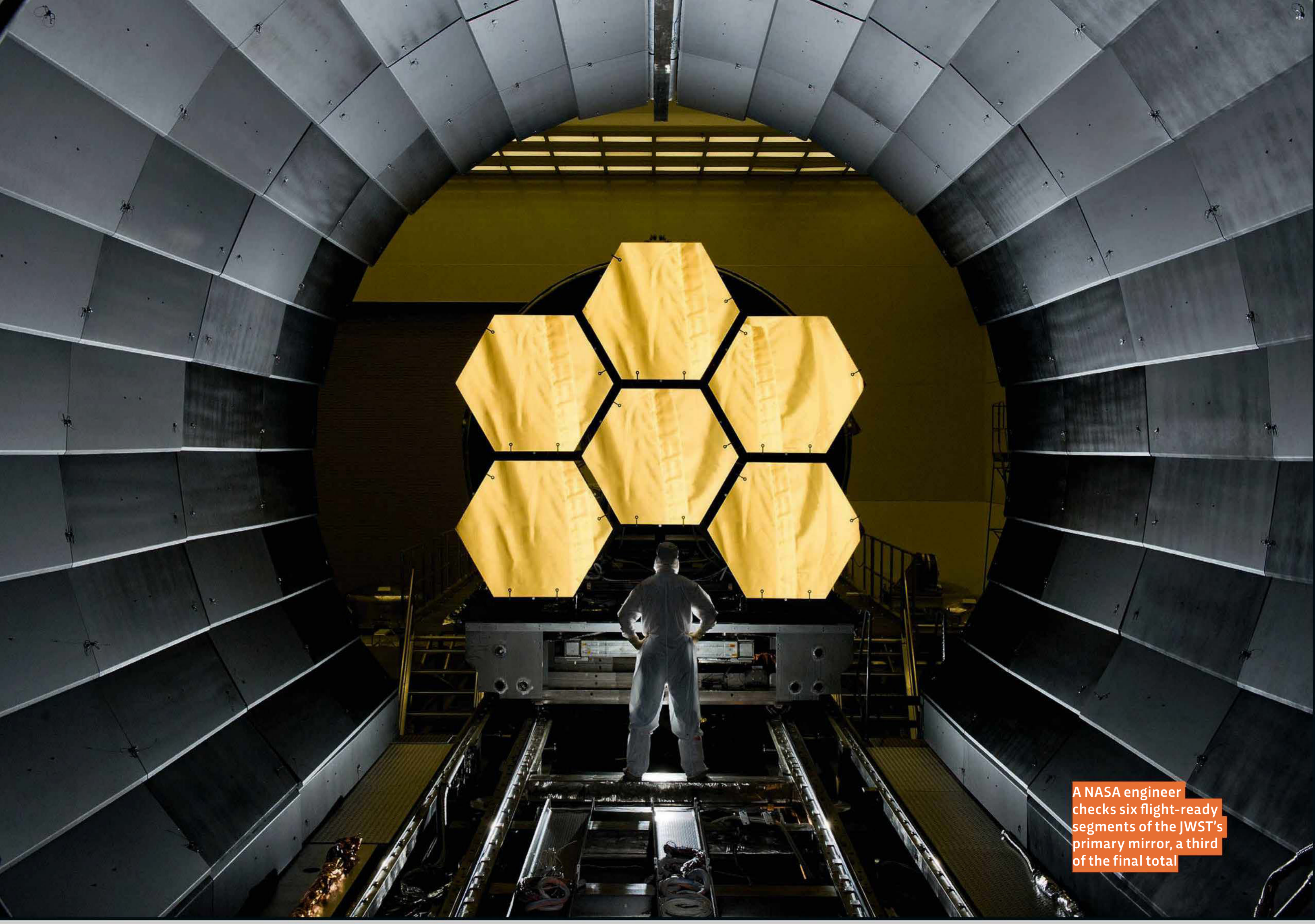

A NASA engineer checks six flight-ready segments of the JWST's primary mirror, a third of the final total

THE JAMES WEBB SPACE TELESCOPE

➥ Pete Lawrence

Astronomer and presenter of BBC Sky at Night

Launched aboard an Ariane-5 rocket on Christmas Day 2021, the James Webb Space Telescope (JWST) is nothing short of a technological marvel. Augmenting and improving on the role established by the Hubble Space Telescope, the JWST is designed for infrared astronomy in the wavelength range of 0.6-28.5 microns.

The JWST targets many important areas of astronomy and cosmology, from studying the first stars and initial galaxy formation, to spotting exoplanets and analysing their atmospheres.

A technologically and financially ambitious project, it hit many snags along the way to final deployment. The JWST's large primary mirror was too large to be carried inside the rocket's payload bay, for one. The problem was solved by designing the mirror so that it could fold up for transit and open like the petals of a flower at its destination.

That destination needed to be far from any bright radiation sources, such as Earth and the Moon, for JWST's extremely sensitive infrared detectors to work. Consequently, its base observation site is located 1.5 million kilometres from Earth, on the opposite side to the Sun. Fortunately, upon its arrival, JWST deployed without incident, which is just as well, because being so distant, there's little we could have done to fix any problems.

In December 2022, JWST discovered the most distant, and therefore earliest, galaxies ever observed. A galaxy survey project called JWST's Advanced Deep Extragalactic Survey looked at an area where Hubble had recorded 10,000 galaxies, and detected a mind-blowing 100,000 galaxies in the same patch of sky. It's not just unfathomably distant objects that have had the JWST treatment, though. Jupiter, Saturn, Uranus and Neptune have all come under JWST's scrutiny, and spectacular new details about each world have been revealed as a result.

As time goes on, JWST continues to break new ground and its observations are challenging existing theories about object evolution, posing many more questions along the way.

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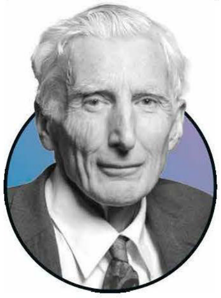


EXOPLANETS

➥ Lord Martin Rees

Astronomer Royal, Emeritus Professor of Cosmology and Astrophysics, University of Cambridge

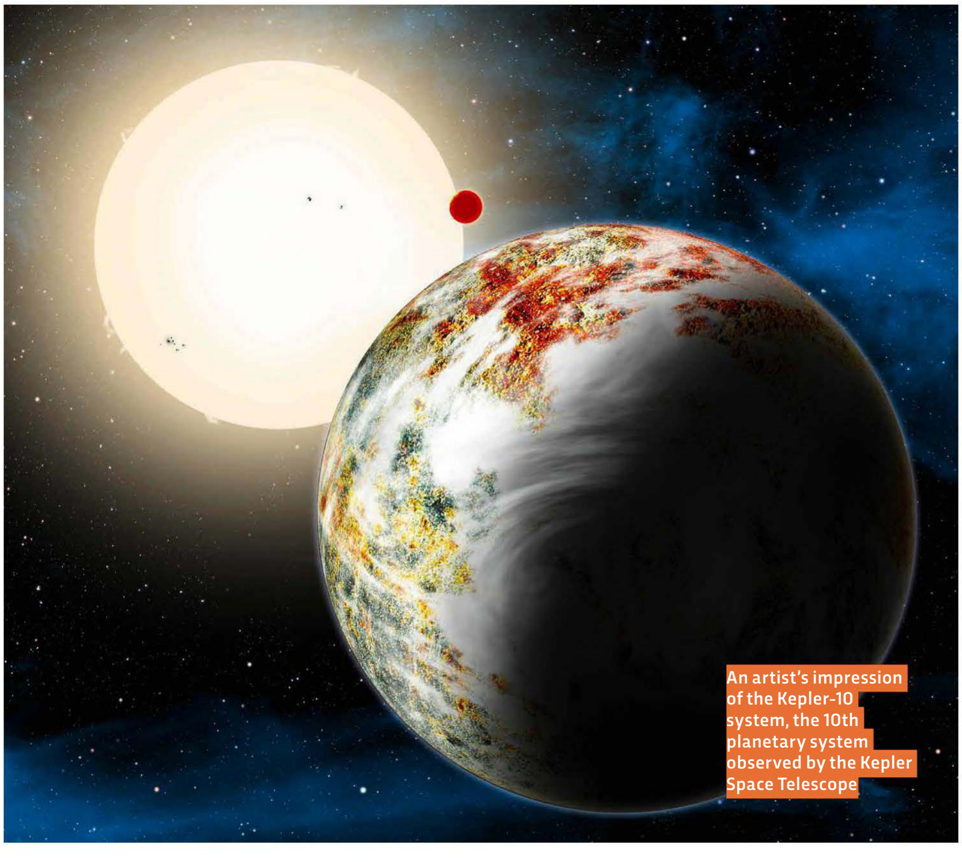
It makes the night sky far more interesting if we think of every star as being at the centre of a system of planets, like in our Solar System. Of special interest is the possibility that many of those planets are like Earth: the same size and at a distance to their parent star that allows water to exist. Could there be life on them?

Though they were officially discovered in about 1995, most of what we know about exoplanets has come in the last few years. We've now detected over 5,000 of them, mainly with the 'transit method.' This is where you don't actually detect any light from the planets, but the effects on the brightness of a parent star when a planet passes in front of it.

The most successful way we've carried out the transit method is by looking through the Kepler Space Telescope. Though the telescope has revealed a lot, it doesn't tell us about what the surfaces of these planets are like. For that, you've got to detect some light reflected from the planet. That's much harder and, so far, has only been done for really big planets, not Earth-sized ones. The challenge for the coming 25 years is going to be detecting the light from the Earth-like planets orbiting nearby stars.

The James Webb Space Telescope may do some of this, but a giant ground-based telescope – the Extremely Large Telescope – is being built by a consortium of European countries in Chile. Its mirror is 39m (128ft) across, so it could collect a lot more light from faint objects than the Webb telescope, which is 'only' 6.6m (21ft) across.

There's so much this new area of study could show us. I think if I were talking to a young person embarking on an astronomical career, I would advise focusing on exoplanets. The field is clearly going to be expanding and full of a high rate of discoveries in the coming decades.



An artist's impression of the Kepler-10 system, the 10th planetary system observed by the Kepler Space Telescope

NASA/JPL X2

...BUT ALSO GRAVITATIONAL WAVES

Gravitational waves are significant for two reasons. Firstly, they're an important physical phenomenon that tells us about the nature of gravity, confirming a further consequence of Einstein's General Theory of Relativity. Secondly, detecting them has been an amazing technical achievement.

The Laser Interferometer Gravitational-Wave Observatory (LIGO) was a huge technical challenge because the expected amplitude of these waves is very small and must be detected at a vast distance. The effect you're looking for is like the thickness of a hair at the distance of a nearby star. Quite amazing.

Many of us thought that LIGO wouldn't find anything. Or, if it did, events would be fantastically rare, the instruments only being sensitive enough to detect collisions once a century or so. But LIGO has been more successful than any of us expected, detecting a pair of black holes about 50 times the mass of the Sun crashing together within a short time of being switched on. It was amazingly exciting and it's now detecting about one or two such events a week. It's worth celebrating for the hundreds of people who were involved with the set-up of these instruments.

The gravitational waves that LIGO observes are a short pulse of radiation of about 100 cycles per second, which is roughly the orbital period of two 50 solar-mass black holes when they merge together. But there are far bigger black holes in the centres of galaxies with masses millions of times higher than LIGO can detect. Mergers of these are much rarer, but can be detectable out to greater distances. The radiation produced, however, is at a much lower frequency.

This has to be detected by instruments that, instead of having mirrors a few kilometres apart, has mirrors a few million kilometres apart.

The ESA-led Laser Interferometer Space Antenna (LISA) is planned to launch within the next 10 years. It should detect the rare mega-cataclysms when galaxies merge and the supermassive black holes in their centres collide.

PSYCHEDELIC THERAPY

➥ Dr Dean Burnett

Neuroscientist and author

Author of *Why Your Parents are Hung-Up on Your Phone and What to do About it*

After much deliberation and campaigning from various interested parties, 2024 saw the United States Food and Drug Administration opt not to approve official use of MDMA-assisted therapy for post-traumatic stress disorder, citing insufficient evidence of the drug's (commonly known as ecstasy) efficacy.

Despite this setback, it's important to appreciate what a substantial breakthrough it is that we've even got to this point. While the benefits of psychedelics have a long history, the previous high-watermark of realising their potential therapeutic applications was in the 1950s and 1960s, when LSD use was widespread.

Unfortunately, a combination of LSD's association with counterculture and President Richard Nixon's 'War on Drugs', resulted in LSD – and psychedelics in general – falling victim to the brutal backlash. Their use was suppressed, both recreationally and in research contexts, for decades.

The loosening of the restrictions on research into psychedelics in the 21st century has produced potent and fast-acting treatments for depression, anxiety, obsessive-compulsive disorders, addiction and even sexual disorders.

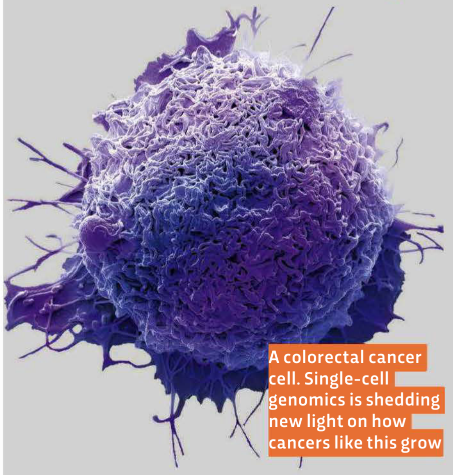
It's still early days for psychedelic therapies. Much of the research remains small-scale and short term, political and ideological barriers remain, and a mainstream rollout of psychedelic therapy would require significant investment.

Even so, especially with the relative stagnation in 'traditional' pharmacological interventions for mental health issues, this growing reassessment of the safety, potency and benefits of psychedelics could prove world-changing.

SINGLE-CELL GENOMICS

➥ Dame Kay Davies

Dr Lee's Professor of Anatomy Emeritus, University of Oxford



A colorectal cancer cell. Single-cell genomics is shedding new light on how cancers like this grow

The human body is made up of almost 40 trillion cells and conventional wisdom suggests these are divided into about 200 cell types. Before the advent of single-cell genomics, our technologies studied cells in bulk, providing an average readout for thousands of cells without resolution of the individual cell identities.

In the human body, as in all multicellular organisms, there are different cell types within the same tissue that have distinct roles: muscle tissue contains subtypes of muscle cells, but also blood vessels, neurons, immune cells and more. Without understanding this complexity, it's impossible to determine how subpopulations of cells in different organs relate to each other and how they might be altered by disease.

In cancer, the DNA of a single cell mutates to allow it to multiply without control, leading to the formation of tumours. The tumour cells then interact with other cells in their microenvironment leading to the spread of the cancer.

Single-cell genomics has the power to resolve the individual cell types and cell states, revealing the pathways that promote tumour growth, allowing for the development of targeted therapy.

Another example is Crohn's disease, where the comparison of healthy and diseased tissue at the single-cell level revealed the reason for a lack of response to therapy in some patients. During the pandemic, single-cell genomics was used to determine which cells are susceptible to infection and later studies determined which organs are most affected and why. These are just a few of the applications of single-cell genomics and the list is expanding all the time.

More than 3,000 scientists around the globe are making a Human Cell Atlas (HCA) to provide a complete single-cell map of all the organs of the human body. This initiative has already led to a paradigm shift in the understanding of the function of normal cells and forms the basis for the understanding of the mechanisms leading to diseases. The progress being made is leading to better diagnosis and treatment.

It has been less than a decade since single-cell analysis was developed and only six years since the HCA was launched. The next decade of single-cell genomics promises to be an even more exciting one.

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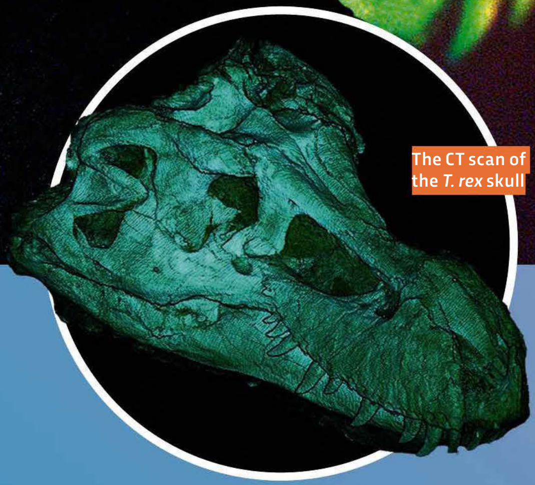
Prof Christopher Brochu took a huge step forward by subjecting a *T. rex* skull to a CT scan



The CT scan of the *T. rex* skull

CT scanning

➥ Prof Steve Brusatte

Professor of Palaeontology and Evolution, University of Edinburgh
Author of *The Rise and Fall of the Dinosaurs*

A little over a century ago, palaeontologists in New York cut open the skull of a *Tyrannosaurus rex*, so they could see inside its brain cavity. It was a bold thing to do, as they had to destroy some of the priceless fossil. But they decided it was worth it, as it was the only way they could try to understand how this most iconic of dinosaurian beasts sensed its world.

Fast-forward to the turn of the millennium, when new technology rendered these destructive fossil surgeries obsolete. In 2000, Prof Christopher Brochu published a scintillating study on the brain, intelligence and senses of *T. rex*. He didn't use a saw; he used X-rays. Brochu put a fossil *T. rex* skull into a computed tomography (CT) scanner.

As the skull was the size of a bathtub, he needed to persuade engineers at Boeing to give him access to the machines they used to scan aeroplane engines to look for imperfections. Although huge, the scanner worked like one a doctor would use at a hospital, using a series of X-rays to build a three-dimensional digital model of the stuff inside the skull. It revealed that *T. rex* had a big brain with enormous olfactory bulbs, which graced this iconic predator with a sharp sense of smell.

Brochu's study wasn't the first CT scan of a fossil, but it made worldwide headlines and sparked a torrent of new research. Suddenly everyone was putting their fossils in CT scanners. Today the procedure is so routine that many palaeontologists have scanners in their labs.

We use them for so many things: to identify hidden bits of fossils still encased in rock, or describe the microtexture and growth marks inside bones to understand how ancient organisms grew and metabolised. They can also help to make digital models that we can subject to computer simulations, testing how dinosaurs fed and moved. To me, CT scanning is the biggest breakthrough in palaeontology over the last 25 years.

NASA'S CURIOSITY ROVER

➡ Dr Stuart Clark

Astronomer, science journalist and author
Author of *The Search for Earth's Twin*

In the kind of PR masterpiece we've come to expect from NASA, they didn't play down the difficulty of landing their Curiosity rover on Mars. Instead, they called it their "seven minutes of terror" and explained that in those 420 seconds, it had to go from a speed of close to 21,000km/h (13,000mph) to zero in order to land safely on the planet's surface.

When they achieved that, the mission's place in history was all but secured, especially since they had used an innovative 'sky crane' landing system, which guided the rover to a much more precise landing than any previous planetary mission.

Then came the science. Since 2012, Curiosity has made ground-breaking discoveries on Mars that help paint a more detailed picture of the planet's past environment, its previous habitability and even its present ability to support life.

It found chemicals and minerals in Gale Crater that indicated the past presence of liquid water, clearly a pre-requisite for life. It then found various organic molecules that serve as the building blocks for life and can be used as food by microbial organisms. While they don't prove that life existed on the planet, they at least show that the correct molecules were present.

But perhaps the rover's most tantalising discovery has been the detection of a seasonal release of methane from beneath the planet's surface. Every Martian summer, the gas has welled up from Gale Crater. While water-rock interactions could be responsible, scientists can't rule out biological activity. The next generation of Mars rovers, such as ESA's Rosalind Franklin will carry subsurface drills to investigate further.

Put together, Curiosity's longevity and its extraordinary scientific results significantly enhance our understanding of Mars, paving the way for future human missions and the search for extraterrestrial life. To seal its place in 21st-century culture, Curiosity also took a selfie (see p6).

...BUT ALSO NASA'S DART MISSION

This entry made one of the biggest impacts both figuratively and literally. On 26 September 2022, NASA's Double Asteroid Redirection Test (DART) mission smashed into the asteroid Dimorphos. The collision destroyed the spacecraft completely and shifted the orbit of the asteroid – all on purpose.

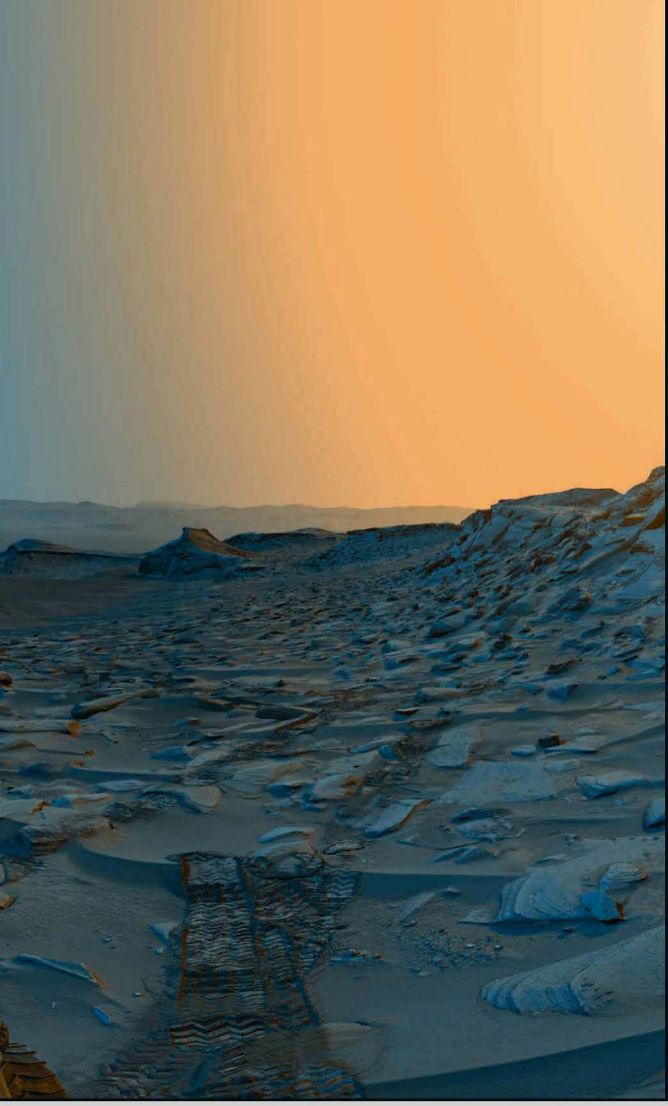
DART was a ground-breaking test of our ability to alter the orbit of a small asteroid, should we detect one on a collision course with Earth – and it succeeded spectacularly. For the first time in history, humankind changed the trajectory of a celestial object and in so doing, proved a method for averting a natural disaster.

The asteroid in question was the smaller component of a double asteroid. The larger of the two is called Didymos. Originally discovered in 1996, Didymos is a chunk of rock with dimensions of roughly 851 x 848 x 620m (2,792 x 2,782 x 2,034ft). Its companion, eventually named Dimorphos, was confirmed in 2003. With a dimension of just 177 x 174 x 116m (580 x 570 x 38ft), it was the perfect test subject for the mission.

Being locked into orbit around Didymos meant that the amount by which it had been moved would

ABOVE Curiosity looks back to capture an image of the Marker Band Valley, where it found signs of an ancient lake

ABOVE RIGHT SpaceX's reusable rockets are bringing down the costs associated with launching people and tech into space



show up in a change of the time it took to circle the larger asteroid. Before the impact, Dimorphos took just under 12 hours to orbit Didymos. After, the impact, this time had decreased by just over half an hour, showcasing a viable method for deflecting potentially hazardous asteroids from Earth.

DART's accomplishments extend beyond planetary defence, though. The mission has provided critical data on asteroid composition and impact mechanics, not to mention celestial navigation by hitting a 100m-wide (328ft) target at speeds of kilometres per second while having travelled millions of kilometres from Earth.

...AND FINALLY, SPACEX'S REUSABLE ROCKETS

For decades, the biggest roadblock to the exploration and utilisation of space has been the cost of launching objects and people into space. The enormous Saturn V, used to transport astronauts to the Moon in the 1960s and 1970s, achieved a cost of around $5,000 (about £3,950) per kilogram lofted into space, but since the 1990s, smaller disposable rockets have only managed to achieve costs of around $10,000 (approx £7.900) per kilogram.

SpaceX has blown that figure out of the water and is currently in the process of revolutionising spaceflight. The game changer was the introduction of the Falcon 9 reusable rocket in 2015. With a first stage booster that could return to Earth and land upright, the cost of launching people, supplies and technology into space started to tumble.

The reusability enabled more frequent launches, again expanding the range of commercial and scientific opportunities that space could offer. For example, it has made SpaceX's Starlink project viable. This endeavour aims to fly thousands of smaller satellites in low-Earth orbit to provide unbreakable global internet coverage.

With Falcon 9, the cost of reaching orbit is around $2,000 (£1,500) per kilogram. The giant Starship rocket that SpaceX is now test-flying is estimated to slash the cost to an extraordinary $200 (£158) per kilogram.

SpaceX's achievements have reshaped the global aerospace industry and mark a pivotal step toward humankind permanently extending its presence throughout the Solar System. But such progress doesn't come without a cost.

The ability to launch so much into space threatens to dramatically increase the amount of space debris, which imperils working satellites and interferes with astronomical observations of the night sky. Hence the innovation that these rockets allow must be understood in relation to the 'environmental damage' that it could bring to Earth's orbits and the night sky in general.

Nevertheless, SpaceX has brought us to a true watershed, not just in science but human history. **SF**

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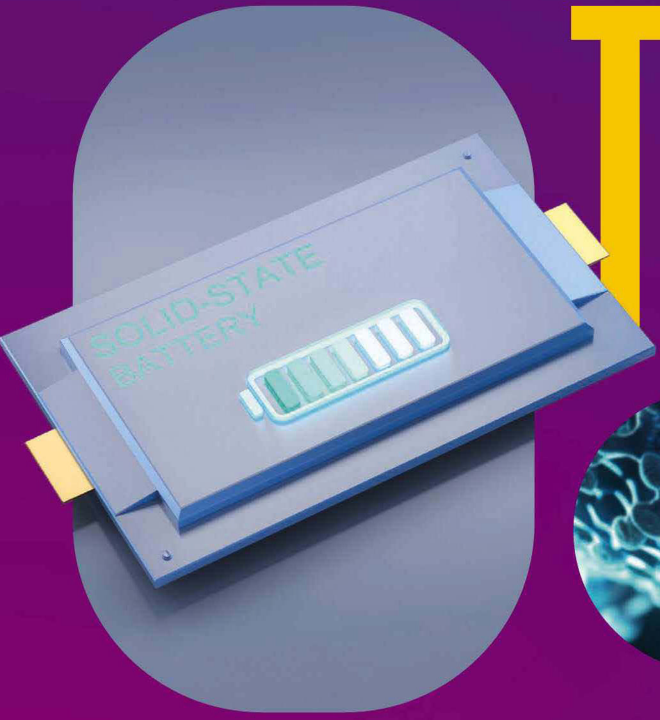
10 IDEAS THAT WILL



Predicting the future is considered a fool's game. But it's one many of us like to play. And seeing as we asked a selection of experts about the biggest breakthroughs of the century so far (p38), we couldn't help but wonder what ideas we'd be talking about in the decades to come… presumably while sitting in a bar on the Moon, sipping anti-ageing, dark matter martinis.

Hundreds of scientific papers cross the *BBC Science Focus* news desk every week, so there are plenty of 'tea leaves' for us to read in the hopes of discerning the direction that tomorrow's winds may be blowing. And so, with the fool's game proviso above, here's our pick of the 10 technologies we think will be defining our daily lives in 2050.

This list is by no means comprehensive, but it is ours. Of course, we would love to hear what your lists look like. Send your predictions to us at reply@sciencefocus.com.

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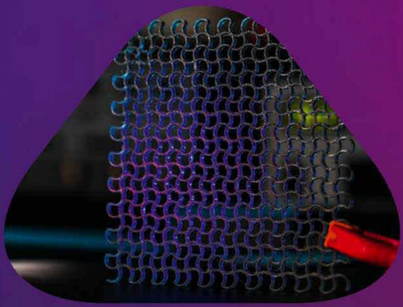
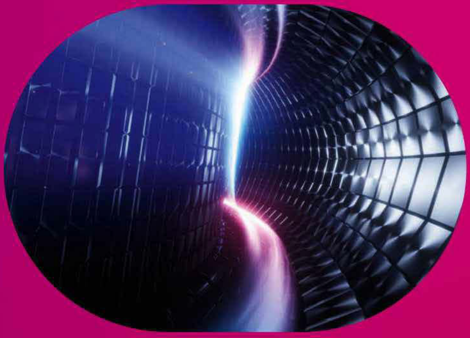
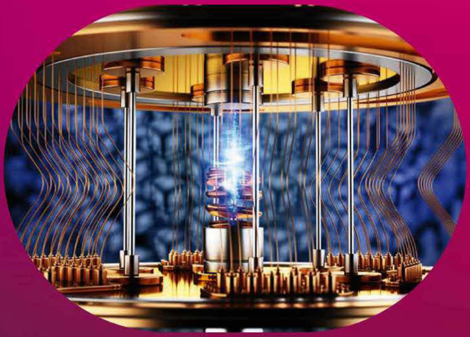






SHAPE THE NEXT 25 YEARS

by **BRIAN CLEGG**

NANO-MEDICS WILL REBUILD US

Nanotechnology works on the minuscule size of nanometres – billionths of a metre. To get a feel for this scale, a human hair is 80,000–100,000 nanometres across.

While the concept of such technology conjures up images of miniature surgical machines, travelling through the bloodstream to operate directly on affected body parts, it's more about making use of the distinctive physical and biological properties that occur at this very small scale.

It becomes possible, for example, to deploy medication directly to the area where it's needed, reducing the chances of it damaging the body's mechanisms along its way. This would also reduce the chance of the body's defences stopping the medication before it reaches its goal.

Much modern conventional medicine depends on designer molecules, which is a form of nanotechnology, particularly with the development of mRNA vaccines such as those used against COVID-19.

But the term is more dramatically applied to indirect mechanisms that don't exist yet. One example likely to be commonplace by 2050 is using nanotechnology to access the brain. This is protected by the blood-brain barrier, a structure that recognises and rejects most pharmaceuticals. But by placing them in specially engineered nanoparticles, there's the potential to transport a drug through to the brain to take direct action on conditions such as Alzheimer's.

Similarly, using nanotechnology for chemotherapy drugs could ensure they only act at a desired site instead of wreaking havoc on the whole body.

The technology could even improve imaging. By deploying special iron-oxide nanoparticles to concentrated areas, doctors could improve the contrast achieved in MRI scans.

Although we're unlikely to see nano-surgeons converging on tumour sites anytime soon, it's certain that the use of nanotechnology, possibly combined with advancements in metamaterials will enable more complex procedures at the nano-level.

SPACE EXPLORATION BECOMES BIG BUSINESS

"IT'S POSSIBLE, FOR EXAMPLE, TO DEPLOY MEDICATION DIRECTLY TO THE AREA WHERE IT'S NEEDED"

The golden age of science fiction featured stories of asteroid or lunar miners, transferring the American Wild West mentality into space. It's already technically feasible to mine materials from the Moon or the asteroid belt, and it has the potential to be extremely profitable.

For example, there could be 10 times as much of the isotope helium-3 on the Moon than there is on Earth, and much of it is near the Moon's surface. This may be a valuable resource for nuclear fusion reactors.

Although the asteroids are much further away, cutting off parts of them, or moving all of an asteroid by attaching a rocket, would be a relatively easy way to haul them back to Earth.

The most likely resources would be rare metals, particularly those used in electronics, though there's a danger that a single asteroid could contain so much material that the market would collapse. Those who believe we'll colonise Mars also see asteroids as a potential source of water.

According to Dr Andrew May, author of *The Space Business*, "Something like asteroid mining looks feasible enough on paper – in engineering terms, at least. But from a business perspective it's iffy, because a company might need to invest a decade or two developing the technology before seeing tangible returns."

However, he points out that as "governments are generally less averse to long-term projects", they could put the brunt of their efforts into a more readily abundant space resource: solar energy.

Solar panels on Earth only receive a fraction of the sunlight that's accessible from space. If this energy could be beamed down to Earth using microwaves, we would have a sustainable surplus of solar energy on tap. This has already been tested on a small scale in 2023, but China plans to have a space solar power station active by 2050.

GETTY IMAGES, SCIENCE PHOTO LIBRARY

A REPLACEMENT FOR CHEMICAL BATTERIES

SOLID-STATE
BATTERY

Climate change makes ditching fossil fuels a priority. In transport, the single biggest barrier to this is battery technology. Current lithium-ion batteries are great for small devices, but have serious limitations for vehicles, in terms of capacity, charge time, durability and safety.

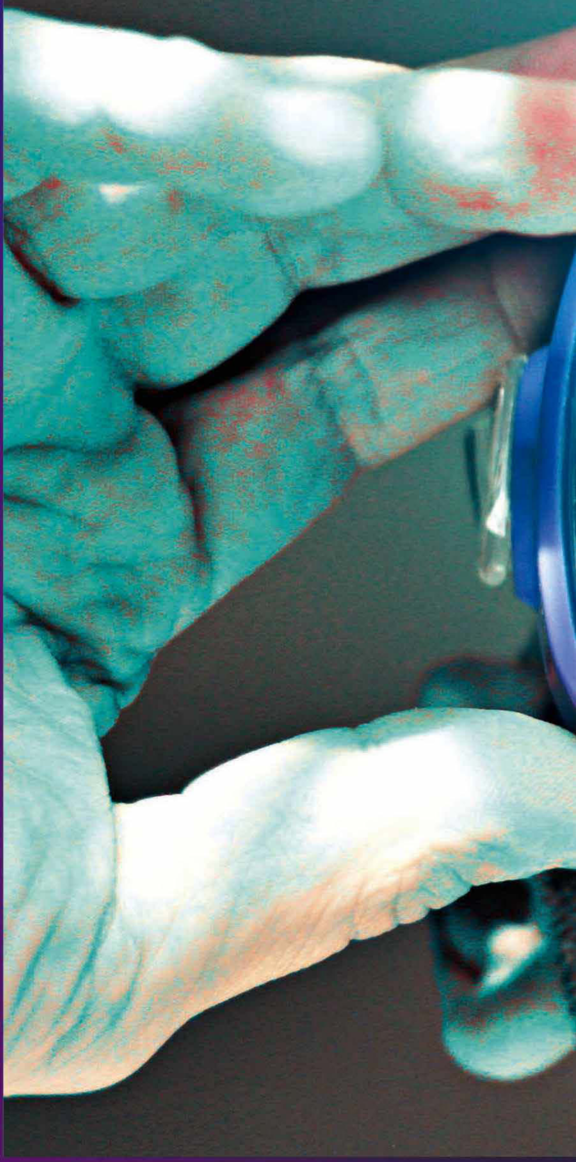
By 2050, we'll likely see a completely new take on battery technology, with a host of new components. Electrodes, and the electrochemically active material between the electrodes, will be replaced altogether.

Dr John-Joseph Marie, a principal analyst at the Faraday Institution, notes that, "Many new battery chemistries are under development that may be in widespread use by 2050. Portable electronics, where energy density is so important, will increasingly rely on silicon anodes to reduce the size of batteries while maintaining the same power output."

"New battery chemistries, such as flow batteries or metal-air batteries, may also be used for ultra-long duration energy storage."

It's also quite likely that supercapacitors will revolutionise electric vehicles. Unlike a battery, which stores energy in an electrochemical reaction, capacitors build up electrical charge on their electrodes – common components used in practically all electronic devices. Supercapacitors add a structure to these electrodes that enables them to hold a double layer of charge. This engages a battery-like phenomenon called 'pseudocapacitance', allowing it to store incredible amounts of energy.

All this to say, supercapacitors charge up in seconds. And where a lithium battery degrades after a few thousand charges, supercapacitors survive for around half a million cycles.



WE'LL ALL USE COMPUTERS LIKE IRON MAN

GETTY IMAGES, ALAMY

One of many sci-fi promises yet to materialise is the transformation of flat, 2D computer interfaces into free-floating dazzling pixelated visions that dance in front of our eyes and react to the wave of our hands.

Currently, spatial computing is available – think technology like Google Glass and Apple Vision Pro – to bridge the gap between our world and the digital realm. It can track eye movements and recognise voice commands, but seems pretty stilted next to what Tony Stark used in the *Iron Man* movies (not to mention pricey and niche).

However, the development of the technology is now well on its way. While eye tracking is currently used to see what the user is looking at, developers are working towards versions able to respond to facial expressions in the way a human can. We can also expect better hand tracking, so that a user can appear to directly interact with the superimposed digital world.

Currently, the biggest obstacle facing spatial computing is persuading people that it's worth having a 650g (1.5lb) headset strapped to their face at all times. Not only does this quickly get uncomfortable, but it looks very odd from the outside. A bulky 2025 headset might be fine for gaming at home, but would likely turn a few heads if you wore it walking down the street. It's likely that spatial computing will only take off, if it can be built into hardware no more obtrusive than a pair of glasses.

Still, look how far mobile phones have come since the turn of the century. We've raced from their basic inception to make them smarter, smaller and more sophisticated than previously thought possible. The average weight of a phone was just 148g (about 5oz) in 2019, and think how far we've come since then. Who knows, by 2050, we might all have upgraded from iPhones to hologram-based eye phones.

THE DOCTOR WILL SEE YOUR DIGITAL TWIN

It may sound like a new type of deepfake, but digital twins are a concept that's ready to rock the medical world.

Where regular computer simulations replicate the behaviour of objects or situations, a digital twin adds a layer of realism. The simulation is fed real-time data from the original object, enabling it to more accurately match what's really going on.

The concept originated with NASA, but has rapidly developed to support a range of tasks. For example, a digital twin can both monitor the state of a nuclear power station and use up-to-the-minute data to predict its behaviour. As you might imagine, this could be particularly useful in preventing potential meltdowns.

By 2050, though, the most familiar digital twins might be our own. We already have smartwatches and other devices that monitor things like our heart rates and blood pressure. Our digital twins could use this data to assess our health, waltzing off to the doctor's surgery to get help before we're even aware there's a problem.

Dr Roger Highfield, co-author of *Virtual You*, writes that, "Simulations are already in regular use in drug development and they'll become more common, providing truly personalised and predictive medicine."

"Hundreds of digital twins of a single patient could explore their virtual futures and the long-term effects of treatments, diets and lifestyle changes. While the most sophisticated twins might be limited to researchers or the rich, simpler versions will allow everyone to benefit from this greater emphasis on prevention."

CRISPR STARTS EDITING OUR GENOME

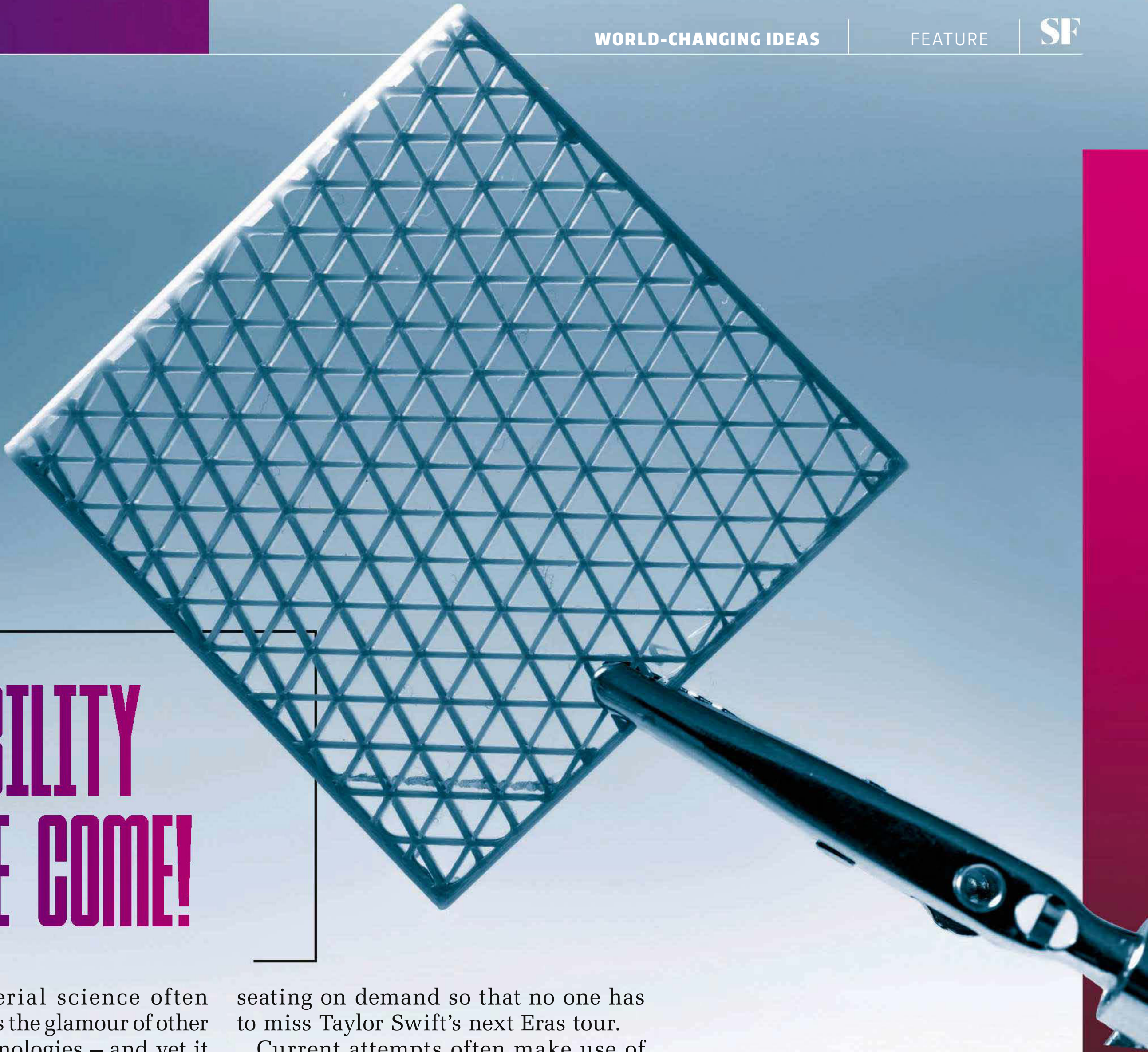
For decades now, we've been promised that gene editing (making direct changes to human genes) will transform healthcare with tailored solutions to medical problems. But the next 25 years could see it come to fruition.

Tools that make precise changes to genes are available now, notably CRISPR. It was used on human embryos for the first time by Chinese scientists in 2015 in an attempt to correct a gene defect responsible for the disease beta-thalassaemia. Though these were non-viable embryos, it highlighted controversies facing CRISPR's medical use and in most of the 86 embryos, the procedure was unsuccessful.

CRISPR has also been studied for treating both viral and bacterial infectious diseases, as well as a range of cancers. Since 2019, when the technology was first injected into a human body, a number of clinical trials have been established, but there are obstacles facing its regular use, both from a safety and ethical standpoint.

Dr Nessa Carey, author of *Hacking the Code of Life* predicts that, "by 2050, we'll see a relatively routine use of gene editing in the treatment of people with inherited disorders, and with some other conditions such as cancer."

"I think by then we'll also see the editing of embryos from families with inherited conditions for which there may be no other effective options. Though technical challenges will be resolved before the ethical ones, by mid-century I doubt we'll be able to justify withholding this option from desperate families."



INVISIBILITY HERE WE COME!

Material science often lacks the glamour of other technologies – and yet it could be an exciting field to watch over the next 25 years. Perhaps one of the simplest yet most promising new materials is self-repairing concrete. Self-repairing is a 'biomimetic' process – one where technology is developed inspired by the capabilities of the natural world – as it echoes the abilities of living tissue to repair damage.

We can expect most concrete of the future to heal itself, using, for example, dormant bacteria that produce calcium carbonate when water gets into the material. Or even filler-like healing agents that are released when microcapsules are broken as the material shifts.

In sci-fi, we often see exotic material that can reshape itself when needed (think *Terminator 2*'s T-1000 melting through prison bars and taking the forms of its various victims). Programmable substances might have more positive uses in the real world. For example, stadiums could be programmed to provide new seating on demand so that no one has to miss Taylor Swift's next Eras tour.

Current attempts often make use of 'solid-liquid phase change pumping', where a material shifts between solid and liquid states, reshaping before solidifying. To date, this has only been possible on a small scale, but over the next 25 years, we could see the approach expand to a practical level.

Perhaps the most exciting new materials, though, are metamaterials. Designed with unusual structures made to hijack quantum phenomena, they can gain unexpected super-abilities.

At the simpler end, these metamaterials might improve safety helmets by changing how much pressure they can resist. On the more spectacular end, scientists are working on honest-to-goodness invisibility cloaks. The metamaterial in these cloaks can bend the light around them, preventing objects underneath from being seen. Currently, the cloaks have only worked on small items, illuminated with non-visible, infrared light, but by 2050 we can expect materials capable of making small items disappear in visible light.

> "THE METAMATERIAL IN THESE CLOAKS CAN BEND THE LIGHT AROUND THEM, PREVENTING OBJECTS UNDERNEATH FROM BEING SEEN"

ALAMY X2, GETTY IMAGES

GETTY IMAGES

QUANTUM COMPUTING POWERS THE NEXT GENERATION OF AI

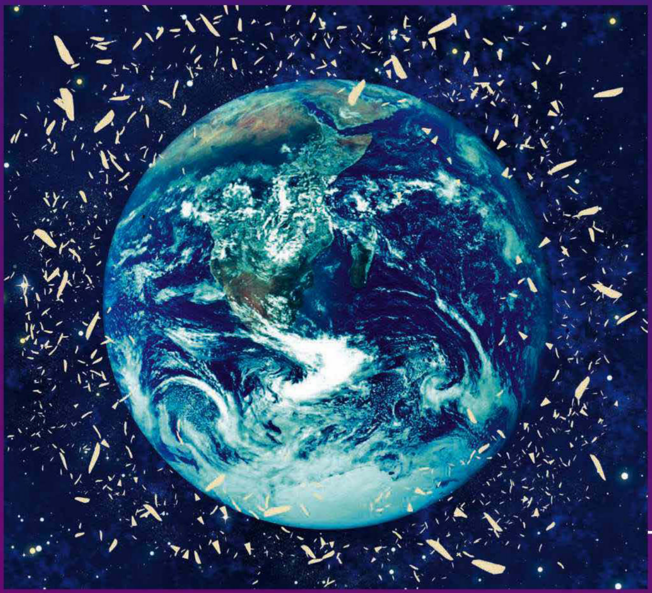
Quantum computers are well on the way to performing calculations that would take conventional machines the lifetime of the Universe to complete. Though currently very limited and error-prone, algorithms are already being developed so that they can, for example, gain the ability to search exponentially faster than their conventional counterparts.

By the time we reach 2050, we can expect quantum computers to be stable enough to be used as everyday remote servers, particularly where complex searching is required. At the moment, most quantum computing is limited by its need for laboratory conditions – for example, to bring materials to ultra-low temperatures. But with the amount of research effort going into improving them, it's likely that this won't be an issue in 25 years.

Quantum computers will also likely be capable of completing multiple calculations simultaneously, transforming the capabilities of artificial intelligence.

While we might not see artificial general intelligence – computers capable of human-like thinking and feeling – in the next 25 years, quantum AI might be able to better explain the reasoning behind its decision-making processes. This would make it more trustworthy when handling tasks that could greatly impact human lives – think healthcare and finance.

ORBITAL CLEAN UP



Our skies are a mess. For decades we've been sending artificial satellites into Earth's orbit, and recently the launch of SpaceX's Starlink has hugely accelerated how much is floating around up there.

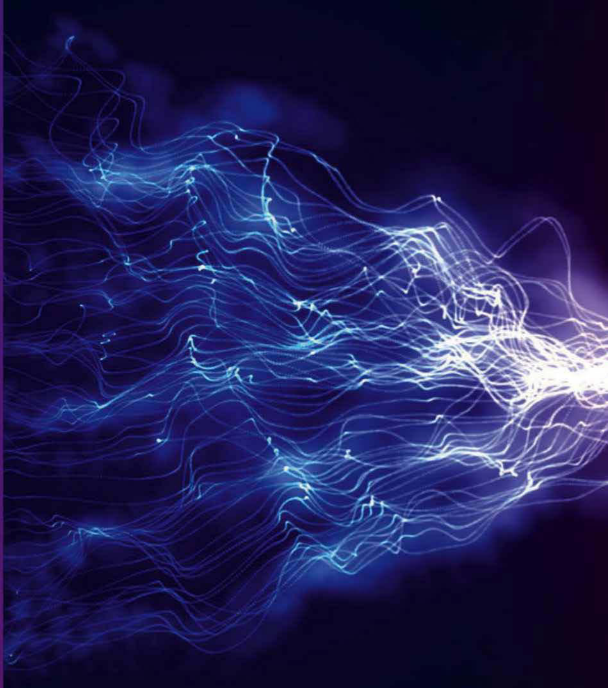
At the same time, smaller orbiting debris is accumulating, ranging from flecks of paint to parts of exploded rocket stages. This stuff is moving fast. According to NASA, the average impact speed of debris is 36,000km/h (22,369mph). Being hit by just a 1cm (0.3in) piece at this speed is like being hit by a bowling ball at nearly 500km/h (310mph).

There are more than 25,000 known objects bigger than 10cm (4in) in diameter currently orbiting us, and tens of millions of pieces overall. The International Space Station regularly receives small dents from tiny debris and has to steer to avoid larger pieces about once a year. By 2050, the situation will be far worse.

Some debris is self-disposing as many objects fall back to Earth. The higher the orbit, the longer this takes: debris in low Earth orbits will usually be gone within a few years, but 1,000km (620 miles) up it can take a century.

Typically, larger objects re-enter at a rate of between one every three days and three a day. Geostationary satellites, flying at an altitude of 35,786km (22,236 miles) to orbit at the same rate as Earth rotates, are usually moved to higher 'graveyard orbits' to clear space, while lower flying satellites are now often intentionally brought down.

By 2050, a range of techniques will likely be used to dispose of debris, including capture vehicles, nets and lasers to vaporise the debris or slow it down so that its orbit decays. Unfortunately, a lack of cooperation between states, commercial operators and space agencies may limit effective debris clearance.



GETTY IMAGES X2

AND FINALLY, FUSION

For decades we've been promised that nuclear fusion would provide clean, green energy and finally – *finally* – by 2050 the promise might deliver.

The concept is simple: harness the power source of the stars. Where current nuclear energy depends on fission (splitting atoms), fusion makes use of the energy released when atomic nuclei merge to form new elements, converting a small amount of matter

to energy in the process.

This has many advantages over fission. It produces far less radioactive waste, uses more easily obtained fuel and has no potential for a meltdown.

Stars rely on immense pressure from their gravitation, as well as high temperatures. Without that, a fusion generator on Earth typically runs at far higher temperatures. Reactors either work by heating plasma to intense temperatures and high pressure, or by using powerful lasers to blast small fuel pellets inwards, producing intense pressure and heat.

Fusion experiments started in the 1950s, with an expectation that they would join the power grid within about 30 years. With the pressure of climate change driving a move away from fossil fuels, it seems likely that fusion will be generating significant amounts of power by 2050.

But Dr Sharon Ann Holgate, author of *Nuclear Fusion*, provides a note of caution: "It's hard to predict when – or even if – we'll be boiling our kettles via fusion-generated power, but I'm hoping it might start feeding electricity into grids worldwide within the next 25 years."

She also points towards the increasing diversity of the technology as a promising sign. "We might see a range of fusion technologies being used depending on the size and location of the reactor: microreactors for instance could use a different technological approach to larger scale power plants."

by **BRIAN CLEGG**

Brian is an award-winning science writer and the author of over 40 books.

THE WORST IDEAS OF THE 21ST CENTURY (so far)

by **IAN TAYLOR**

NOT ALL IDEAS CAN BE HITS. ALONGSIDE GROUND-BREAKING INNOVATIONS, 21ST-CENTURY SCIENTISTS HAVE HELMED THEIR SHARE OF WILD TECH FLOPS, DUBIOUS THEORIES AND OVERHYPED BREAKTHROUGHS. HERE ARE THE BIGGEST TO FORGET

ENVATO ELEMENTS

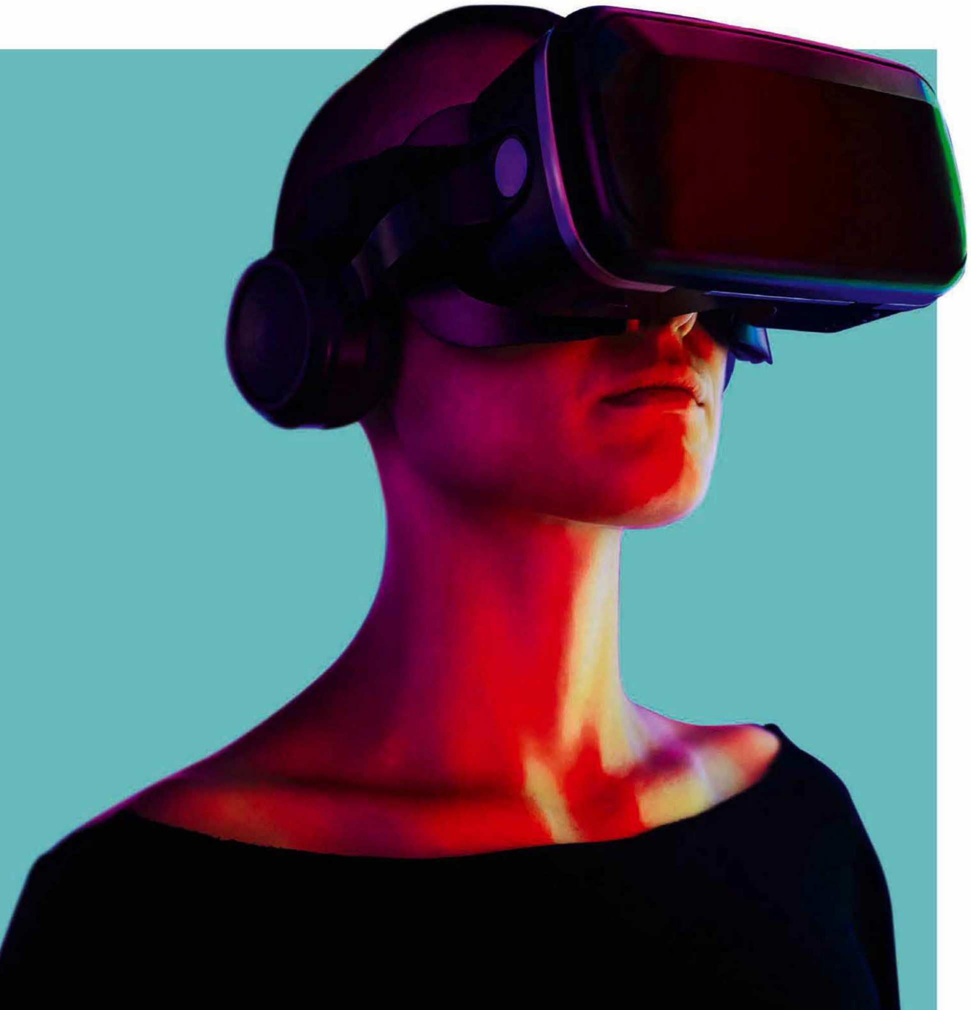
THE METAVERSE

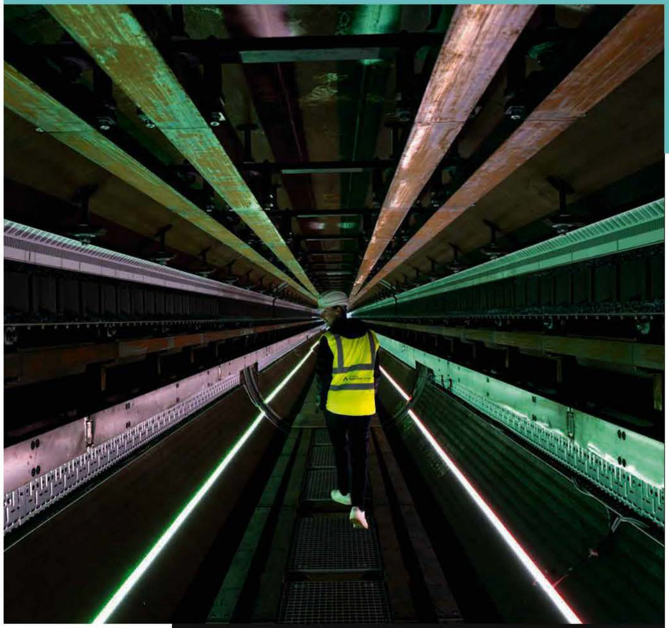
If you don't know what the metaverse is (no judgment because it was horribly sold), it was a word that Mark Zuckerberg and roughly four other people used to describe loosely connected immersive technologies such as virtual reality (VR), augmented reality (AR), open-world gaming, digital avatars and non-fungible tokens (NFTs). The internet 3.0, if you will.

Zuckerberg imagined a terribly animated dystopia where we could work and socialise on a hybrid plane of semi-digital existence. We would have avatars to attend meetings for us, but for some reason, they wouldn't have legs. You could buy a mansion made of pixels, not bricks. Pop-up notifications would bombard our retinas via AR glasses that superimposed online content over the real world. And thanks to VR, we could do anything or go anywhere simply by strapping a heavy, sweat-inducing computer to our faces.

Some of these technologies are still fighting for life, but many have faded from relevance or completely stalled.

Zuckerberg's VR branch has now lost a staggering $58bn (£46bn) since 2020. Don't expect those losses to be a blip – a survey of 624 tech experts found that nearly half believe the metaverse won't play a major role in our lives, even by 2040.





HYPERLOOP

From an engineering perspective, hyperloop is a bold, world-changing form of transport – if only someone could get it to work. The idea is to encase people and cargo in a steel tube, then propel them with magnets through a near-vacuum at 1,000km/h (about 600mph), hopefully without rearranging anyone's internal organs.

Elon Musk wrote a white paper on the concept in 2013 and multiple start-ups and test tracks have since been built around the world. Critics say Musk vastly oversimplified the construction and infrastructure work required to make hyperloop a reality. Some even claim he only proposed it to shut down high-speed rail proposals to the benefit of his electric car company, Tesla.

Whatever the truth, a Dutch hyperloop company conducted its first test in autumn 2024. Top speed: 30km/h (19mph).

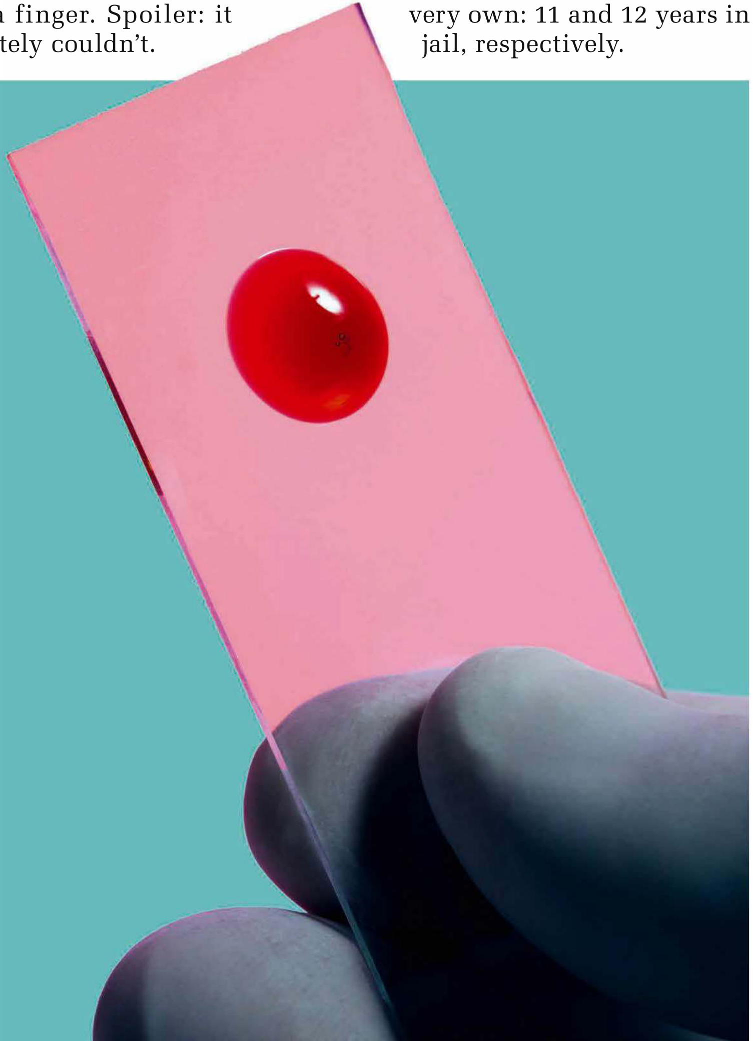
GETTY IMAGES X4

FINGERSTICK BLOOD TESTING… FOR CANCER

Think big, fail fast. Silicon Valley's unofficial motto works well if you're building another social media platform or the next big thing in blockchain-powered fintech management software (is that a thing? We think that's a thing). When 'Big Tech' gets into the health space, however, lives are at stake.

The biggest cautionary tale comes from Theranos, a company that claimed to have invented a blood test that would change the world. It was called Edison – a handheld laboratory that could detect over 200 diseases, cancer included, from a tiny amount of blood extracted from a finger. Spoiler: it absolutely couldn't.

At its peak, Theranos was valued at $9bn (£7.1bn). Its founder, Stanford dropout Elizabeth Holmes, was feted as the youngest self-made billionaire in history. Eventually, whistleblowers came forward, followed by federal investigators. They found that Edison produced unreliable results. One patient was told they were HIV positive when they weren't. Another was told she had miscarried when she hadn't. There were also multiple false diagnoses of cancer and diabetes. By the end of 2022, Holmes and her partner Ramesh Balwani had received a prognosis of their very own: 11 and 12 years in jail, respectively.



3D-PRINTED GUNS

When 3D printers for playing around with at home first hit the market, our minds all leapt to *Star Trek*'s replicators. We dreamed of machines that could materialise tea, Earl Grey, hot – cup and all. Sadly, about five minutes into the 3D-printing-at-home craze, some bright spark created a set of instructions that could print a gun. And just like that, our future looked less like *Star Trek* and more like *The Terminator*.

THE LIKE BUTTON

We could debate the pros and cons of social media all day until we hate each other, but… well, that's what social media is for. Surely one thing we can agree on, however, is the like button. Bad idea. Terrible. As well as creating a new form of social currency that kept us addicted to our phones and needy for the button-press of strangers, it also became a gateway through which 'Big Tech' algorithms understood us.

In 2015, psychologist Prof Michal Kosinski found that, armed only with a person's Facebook likes, a computer model could predict that person's personality better than their family or friends could. Where's the thumbs-down button for this idea?

MICROBEADS

Patents go back to the 1960s, but it was in the early 2000s that microbeads (plastic spheres less than 1mm across) became prevalent in our soaps, toothpastes and practically every other cosmetic. All the better for whiter teeth and smoother skin.

Of course, they were an environmental disaster. Too small to be filtered by sewage systems, they washed out to sea and into the food chain before bans started to roll in from 2014. We probably swallowed them too. In recent years, microplastics have been found in human brains, lungs, testes and other organs, although to be fair, those could also have come from car tyres, coffee pods, food packaging or any number of other sources.

SEGWAY

The Segway was supposed to do for cars what cars did for horses, a revolution in transport that investors claimed would be bigger than the internet. It didn't work out like that. The company vastly overestimated our appetite for two-wheeled 'personal transporters' and didn't even get them certified for road use in a lot of places. Lazy tourists still use them in some cities, but let's be honest, everyone looks a little tragic on a Segway. None more so than British businessman Jimi Heselden, who bought Segway Inc. in 2009. He died a year later, reversing one off a cliff.

CLOSE
NOT CHILD SAFE
TWIST TO OPEN

OVERPRESCRIBING OPIOIDS

"What's that, you're having some moderate discomfort? Here, have a bottle of wildly addictive tablets and we'll see you again when you overdose." We're reasonably certain that no doctor has ever said those exact words, but some of them might as well have. Between 1998 and 2016 opioid prescriptions in England increased by 127 per cent, according to *The Lancet*. A sharper rise has been seen in the US, where an estimated 17 per cent of the population have filed at least one opioid prescription.

It's also a global trend. Researchers estimate that 60 million people are battling the addictive effects of opioids. Close to 80 per cent of the world's deaths due to drugs were related to opioid use.

Overprescription isn't the only factor, but public health experts agree that it's a big one. Egged on by salespeople from 'Big Pharma', physicians spent the early 21st century handing out high-strength painkillers like they were plasters. The result? A deeply upsetting wound in our collective medical records.

ALAMY, GETTY IMAGES X5

NFT ART

GALACTIC
AYLORDS
.COM
DEVIANT ART
Ravegotch
imnotArt

Are rich people okay? This was the question asked in 2021, when NFT artworks started selling for millions.

'Non-fungible tokens' are unique digital assets stored on a digital ledger called a blockchain. To outsiders, buying them looked like people were paying Lamborghini prices for JPEGs.

The most infamous NFT project was the Bored Ape Yacht Club, valued at $4bn (£3.2bn) at its peak in 2022. By 2023, the floor price had collapsed by 88 per cent.

That doesn't mean now is a good time to invest. In 2024, analysts claimed that 96 per cent of all NFT collections were effectively dead.

LOOT BOXES

According to a paper from Harvard Business School, gamers spend $15bn (£11.8bn) a year on loot boxes. These collectable in-game tokens give your character a cooler outfit or a weapon that will smite your enemies more brutally and efficiently. All good fun.

Except, for many players, in-game purchases have ruined the experience. Critics say that high-profile console and mobile games are now designed to maximise loot box revenue at the expense of playability. To advance in many games, you have to keep spending. This pay-to-win model is often compared to gambling and can encourage addictive behaviours in young gamers. We'd rather KO this custom.

07
82
WARNING
Contents
may vary.

GOOGLE GLASS

It's funny, isn't it, how many so-called smart products are designed with the bare minimum of common sense. Google Glass may be the ultimate example, the head-mounted wearable lasting all of two years on the market before being discontinued.

It looked like something from *Star Trek*. The device had a tiny display that put the internet just millimetres from your eyeball, so you could access sweet, sweet content at any moment. Finally, you could take a scenic walk while reading your inbox hands-free. Or scroll social media while visiting your grandmother, updating her in real time on the latest celebrity divorces. She'd love that.

Google Glass also included a camera to record Nana's reaction, but also everything and everyone, all the time. It gave us the creeps just as much as it gave privacy campaigners an open goal the size of the Grand Canyon.

Google halted production in 2015, but recently a slew of new, but no-less-creepy, prototypes have emerged.

HEALTH HALO FOOD LABELS

A weird paradox of the 21st century is that while people are more health-conscious than ever, our diets now include more unhealthy and processed foods than at any point in history. In the US, for instance, ultra-processed foods account for more than half of all calories consumed. Meanwhile, food labels are stuffed with buzzwords that make products seem healthier than they actually are.

A box of granola may be 'organic', but it could still pack enough sugar to make your eyeballs hum. A 'high-protein' ready meal might also be swimming in trans fats. And that loaf of 'multi-grain' bread sounds good, but if it's made with refined grains, then much of the fibre and many of the nutrients will be stripped away during production. You'll also find plant-based foods labelled 'cholesterol-free' when, in truth, all plant-based foods are cholesterol-free.

This effect works the other way, too. Most scientists believe genetically modified foods have incredible potential for public health, but many consumers are put off by the label. Meanwhile, foods splashed with vapid, unscientific labels are regularly sold as health foods.

Oh, it's '100-per-cent natural', you say? Great. So is arsenic.

100% organic

POWER POSING

Chest out, shoulders back, chin up. The flaky field of body language was supercharged in 2010 when researchers from Harvard and Columbia found that certain poses make us feel more powerful and in control. Not only that, the right 'expansive' poses – such as reclining with your hands behind your head – could reduce stress hormones and increase testosterone.

The idea caught on quickly. Peacocking CEOs strutted around the board room and people questioned why politicians were delivering speeches while standing like a superhero.

Five years later, power posing lost a lot of its presence when researchers realised that some of the results of the original study couldn't be replicated. In fact, confidence in the whole field of social psychology was faltering in what has since become known as 'The Replication Crisis'. Still, we're sure it's nothing a strong handshake couldn't sort out.

MARS ONE

Wanted: 40 brave souls to build the first human colony on Mars. The year was 2011 and Dutch entrepreneur Bas Lansdorp had a dream to send human beings to the Red Planet. The catch? Mars One would be a one-way trip.

That didn't seem to put people off, neither did Lansdorp's plan to fund your slow death in part with a *Big Brother*-style reality TV show.

Scientists and aerospace engineers were aghast, and listed serious misgivings about hardware, logistics and the health of astronauts. They needn't have worried. Mars One went bankrupt in 2019.

ALAMY X3, GETTY IMAGES X3

FACEBOOK RUNNING EXPERIMENTS ON US

facebook
Home
Profile
Friends
News Feed
Live Feed
Status Updates
Pages
What's on your mind

The big tech firms that emerged in the noughties gathered more personal information on their users than any corporation in history, and not always with our best interests at heart. Case in point, in 2014, Facebook – early motto: move fast and break things – ran an experiment on 700,000 users without their knowledge.

The delightfully Orwellian study aimed to manipulate people's emotions by controlling what turned up in their news feeds. Beyond privacy concerns, critics slammed social media's ability to choreograph people's moods and influence their political opinions. Facebook (now Meta) apologised though, so no harm done.

OVERPROMISES

The early 21st century has been a time of fast and giddy discovery across many fields of research. But, like all *Homo sapiens*, scientists are sometimes guilty of getting ahead of themselves. This century alone, we've been promised warp drives and cold fusion, personalised medicine and tepid semiconductors. And every time there's the smallest breakthrough, researchers say the world-changing development will be with us in five-to-ten years. It's always five-to-ten years. Maybe they just say that to make sure the research keeps getting funding. Still… better get a move on. The 22nd century is only 75 short years away.

GEOENGINEERING

Such is the scale of the climate crisis that rational scientists think it might be a good idea to spray aerosols into the upper atmosphere to bounce sunlight back into space. Others plan to cover deserts and glaciers with some kind of sheeting. There are also proposals to meddle with the weather or boost the oceans' alkalinity.

Pretty much every geoengineering plan is controversial, their results uncertain and their side effects unknown. But, you know… nothing ventured, nothing gained. Climate talks are failing and decarbonisation is too slow. Might as well shoot for the Moon, eh, folks?

In the words of the American writer Eli Kintisch, geoengineering is a bad idea whose time has come. **SF**

by **IAN TAYLOR**

Ian is a freelance science writer and the former deputy editor of BBC Science Focus.

THE BIG QUESTION

How can I change my personality?

Want to become more confident, extroverted or assertive? Science shows that with a few simple changes, you can unlock your best self

by **DR CHRISTIAN JARRETT**

It's a new year and – as a few thousand vaguely patronising Instagram posts will tell you – it's the perfect time to turn over a new leaf. Start afresh, be better. But where to start?

Well, you could adopt a new hobby or make a meagre New Year's resolution. Or maybe you could get much more radical and change your personality.

In scientific terms, personality is simply a set of traits that reflect how you tend to think, feel and behave. It might sound harsh or confronting to suggest changing your personality, but many surveys suggest that most people wish to alter at least some of their traits.

> **"Consider your personality as being grounded in various habits of thought. To change it, you need to change those habits"**

Psychologists largely recognise there are five key personality traits: openness to experience (your willingness to try new things); conscientiousness (your self-discipline, ambition and orderliness); extroversion (how much you're drawn to fun); agreeableness (how warm, friendly and trusting you are); and neuroticism (how much you experience negative emotions, such as worry and doubt).

Unlike moods or emotions, personality traits are relatively stable. If you don't see your friend for a few years, you still recognise them as essentially the same person when you finally do meet up. It might sound far-fetched, then, to change such a fundamental aspect of ourselves. But psychologists have been stress-testing personality, and their findings suggest that not only is personality change possible, it's actually a jolly sensible idea.

For instance, through a series of studies published in 2023 and 2024, a research team based across various European universities showed that an app was able to help people change their personalities in the ways they wanted. Because of its international inception, PEACH (PErsonality coACH) was only available to download in German – but an English version will soon be on its way.

Few people are happy with all their personality traits, but there are ways to work on adjusting them that might increase your satisfaction with life

GETTY IMAGES

Participants had to choose a trait to focus on and then the app gave them self-help tips, prompting them to adopt activities in line with that trait – such as nudging them to do an important task rather than procrastinating (to boost their conscientiousness), or taking a photo of something beautiful every day (to boost their openness).

PEACH not only shifted the desired traits, but the changes lasted even after a year. What's more, the changes were associated with increases in overall life satisfaction.

Getting started

If you're interested in changing your traits, a great place to start is a personality test that taps into the previously mentioned 'Big Five'. There are various free options online. Have a look at your scores and think about how – and more importantly, why – you'd like to change.

Rather than thinking of your traits in abstract terms, consider your hopes and ambitions in life. What could you change to address those aims? Do you want to increase your extroversion to make more friends? Or boost your conscientiousness to succeed more in your career?

Another approach is to consider how the different traits have been linked with various outcomes in life. For instance, extroverts tend to be happier while neurotic types tend to suffer more from depression and anxiety. Conscientious people generally tend to be more successful in their chosen career paths. Meanwhile, having greater openness has been found to help protect against dementia and agreeable people tend to experience less stress.

A blueprint for change

Psychologists have identified several key ingredients for successful personality change. First, you need to *want* to change. Second, you need to *commit* to doing things differently – that includes changing how you think and behave. Consider your personality as being grounded in various habits of thought and behaviour. To change it, you need to change those habits – that takes dedication, repetition and perseverance.

The PEACH app helped users in this respect by prompting them to think in terms of 'if-then' principles. These are small rules, such as: "*If* I'm waiting in a line, *then* I'll make an effort to talk to the person next to me" (as a method of boosting your extroversion).

Finally, you need to check in, to see how your efforts are paying off and →

→ make tweaks. It's helpful to think of ways to change both from the inside-out (adopting new habits of thought, for instance), and the outside-in (recognising that your environment and the people you interact with also shape you).

If you're serious about changing one or more of your traits, it's worth not only learning new skills and habits, but also taking a look at things like your work culture or your friendship group, to consider whether they're conducive to your personal development goals.

Neuroticism

Surveys show that lowering neuroticism is the most popular change to make. If you succeed, you'll likely benefit – one study from 2013 estimated that a small reduction in neuroticism would boost your wellbeing by the equivalent of an extra $314,000 income per year (that's over $400,000 in today's money, or approximately £312,000).

If you're a high scorer in neuroticism, it's likely that you experience many negative thoughts, such as self-criticism and worry. Schools of psychotherapy abound with tips and tricks for getting these thoughts under control.

One of my favourites is the so-called 'mind-bus' technique. Imagine that you're the driver of a bus and your difficult thoughts are the passengers. You can then have fun, for example, getting them to sing what they're nagging you with, or telling them you're in charge. The idea is to help create a distance between yourself and your thoughts so that they'll trouble you less.

Conscientiousness

After lowering neuroticism, the next most sought-after personality change is to become more conscientious. It's a good choice because more conscientiousness is associated with receiving more work promotions and living longer.

One way to get started is to realise that the secret to higher conscientiousness is not having ironclad willpower. It's about avoiding temptations in the first place.

Psychologists talk about a 'temptation generation cycle' and you can get into the habit of disrupting it at different stages. First of all, you can remove temptations (don't leave the cookie jar out; don't take your phone to bed). Secondly, you can influence your appraisal of temptations – tell yourself that the cookies look old and your phone makes you stressed.

The next step is to make the alternatives sparkle. Remind yourself of how good you'll feel after you've eaten some fruit, or how rewarding it'll be to read a book.

Extroversion

Surveys show the next most sought-after trait change is to become more of an extrovert. This could be a shrewd move – many recent studies have shown that when introverts act more extroverted, they enjoy it much more than they think they will. They've even reported that it makes them feel more authentic.

One fun way to boost your extroversion is to learn a different language that makes you feel less inhibited (research suggests Spanish might be a good choice, but find what works for you).

A completely different approach could be to hone your flirtation skills – yes, really. A study from 2022 found that just three hours of training was sufficient to help make gains in extroversion.

Ultimately, these are just some initial ideas for how you can influence your traits. To achieve any meaningful change, you'll need to stick at it and make a habit of your new ways of living. **SF**

> **"Recent studies have shown that when introverts act more extroverted, they enjoy it much more than they think they will"**

by **DR CHRISTIAN JARRETT**

Christian is a cognitive neuroscientist, science writer and author. He is the author of Be Who You Want.

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Studies suggest introverts often find acting like an extrovert isn't as daunting as they might imagine

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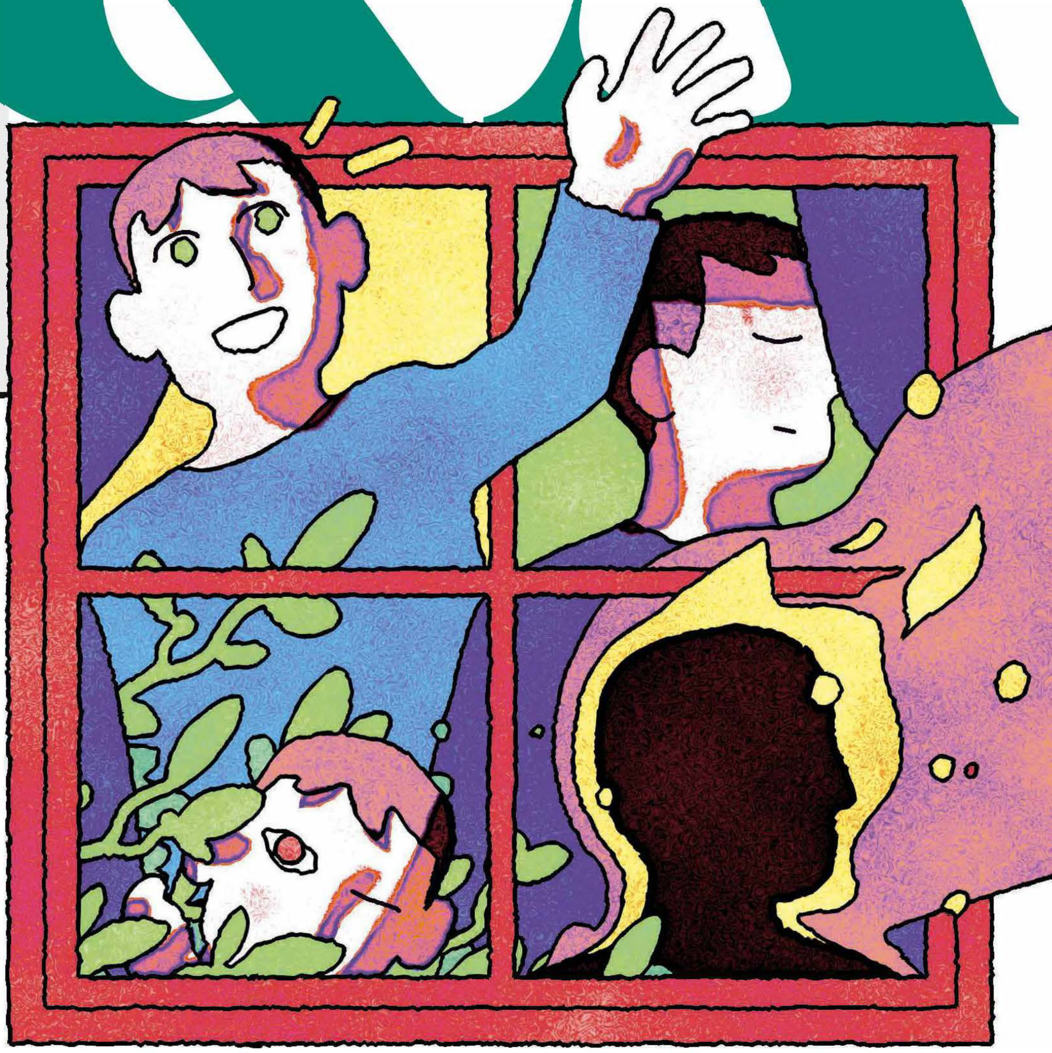
Q&A

YOUR QUESTIONS ANSWERED



GLADYS MOORE, BATH

HOW CAN I IDENTIFY MY PSYCHOLOGICAL BLIND SPOT?

In the 1950s two American psychologists, Joseph Luft and Harrington Ingham, proposed a way of thinking about psychological blind spots – things you don't know about yourself – that they called the 'Johari Window' (the term is a combination of their first names).

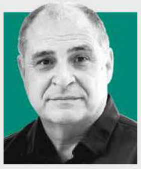
Picture a two-by-two grid, like a window. In one quadrant of the Johari Window is all the things you know about yourself and that other people know about you. Luft and Ingham called this 'free activity', in reference to all the information about you that's freely shared and available.

In another quadrant is all the stuff you know about yourself, but that other people don't know about – you could think of these as your private beliefs or ways that you behave when no one else is around.

The other two quadrants are filled with your blind spots. One of the quadrants contains knowledge and information about you that no one knows – not you and not the people who know you. It's tricky to think what this might be, but perhaps you're changing beneath the surface, slowly shifting in your political beliefs, say, or maybe your tastes in music or film are gradually evolving.

The final quadrant is, in some ways, the most interesting one – this contains the things that other people know about you, but which you don't know about yourself. Maybe other people think of you as lazy, but you don't see yourself that way, or maybe others see you as friendly and sociable, even though you've always seen yourself as more of an introvert.

The Johari Window provided a framework for thinking about these things, but it's only in more recent years that psychologists have conducted research that establishes that people really do have these kinds of blind spots. These days, the ability to discern how other people perceive you is known as meta-perception. The studies suggest that, overall, we're actually pretty good at meta-perception, but at the same time,



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Everyday science

IAN TAYLOR
Health & nutrition

DR ABBIE JORDAN
Biology

> **"THESE DAYS, THE ABILITY TO DISCERN HOW OTHER PEOPLE PERCEIVE YOU IS KNOWN AS META-PERCEPTION [AND] STUDIES SUGGEST THAT WE'RE PRETTY GOOD AT IT"**

most of us do have genuine blind spots – that is, there are significant aspects of ourselves that other people agree on, but which we're ignorant of.

So, how can you find out what your blind spots are? There are some more systematic and scientific ways of going about this, but also some quirkier, less formal techniques that, nonetheless, could end up being rather revealing.

For a systematic approach, you could consider completing a basic personality test (there are plenty of free ones available online – I suggest using one that's based on the 'Big-Five' model of personality, rather than something that's not evidence-based, such as the Myers Briggs). Then ask a sample of trusted friends, relatives and/or colleagues to complete the same test about you. Ask them to be as honest as possible. Finally, compare your test scores with the ones other people gave you and brace yourself for some surprises. In business, this kind of approach is called 360° feedback.

For a less formal approach, you could try a 'dinner of truth'. It's imperative you do this with someone you trust and who you have a strong relationship with. At the dinner, you ask them to tell you one really annoying thing about you that they've never shared before. Tread carefully, but the more people you try this with, the more revelations and blind spots you might uncover. ***CJ***

GETTY IMAGES, ALAMY ILLUSTRATION: KYLE SMART

JOANNA WOODWARD, VIA EMAIL

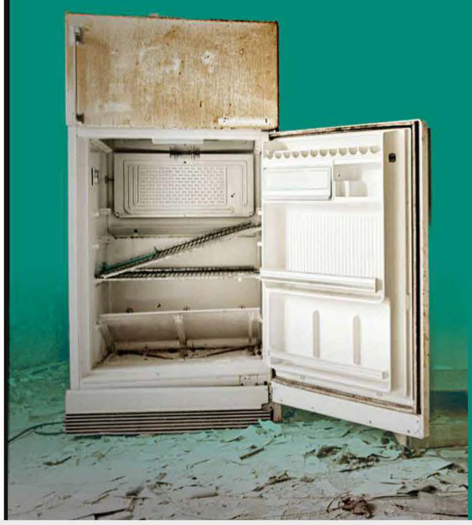
HOW CAN SOME ANIMALS SMELL FOOD FROM SO FAR AWAY?

Nature's finest scent trackers owe their incredible sense of smell to the abundance of olfactory receptors in their noses – or trunks, in the case of elephants. Polar bears, for example, have enough receptors packed into their noses to smell prey from over 32km away (almost 20 miles).

Some dog breeds, like bloodhounds, have up to 300 million receptors (humans have around 6 million). On a good day, dogs can detect food that's 20km (12 miles) away. Additionally, the structure of most dogs' noses, with large amounts of nasal tissue and a high surface area for sensing smell, is designed for scent detection, especially when it comes to finding food. ***AJ***

ERIC DALE, LONDON

HOW MANY PEOPLE ARE KILLED BY FRIDGES EACH YEAR?

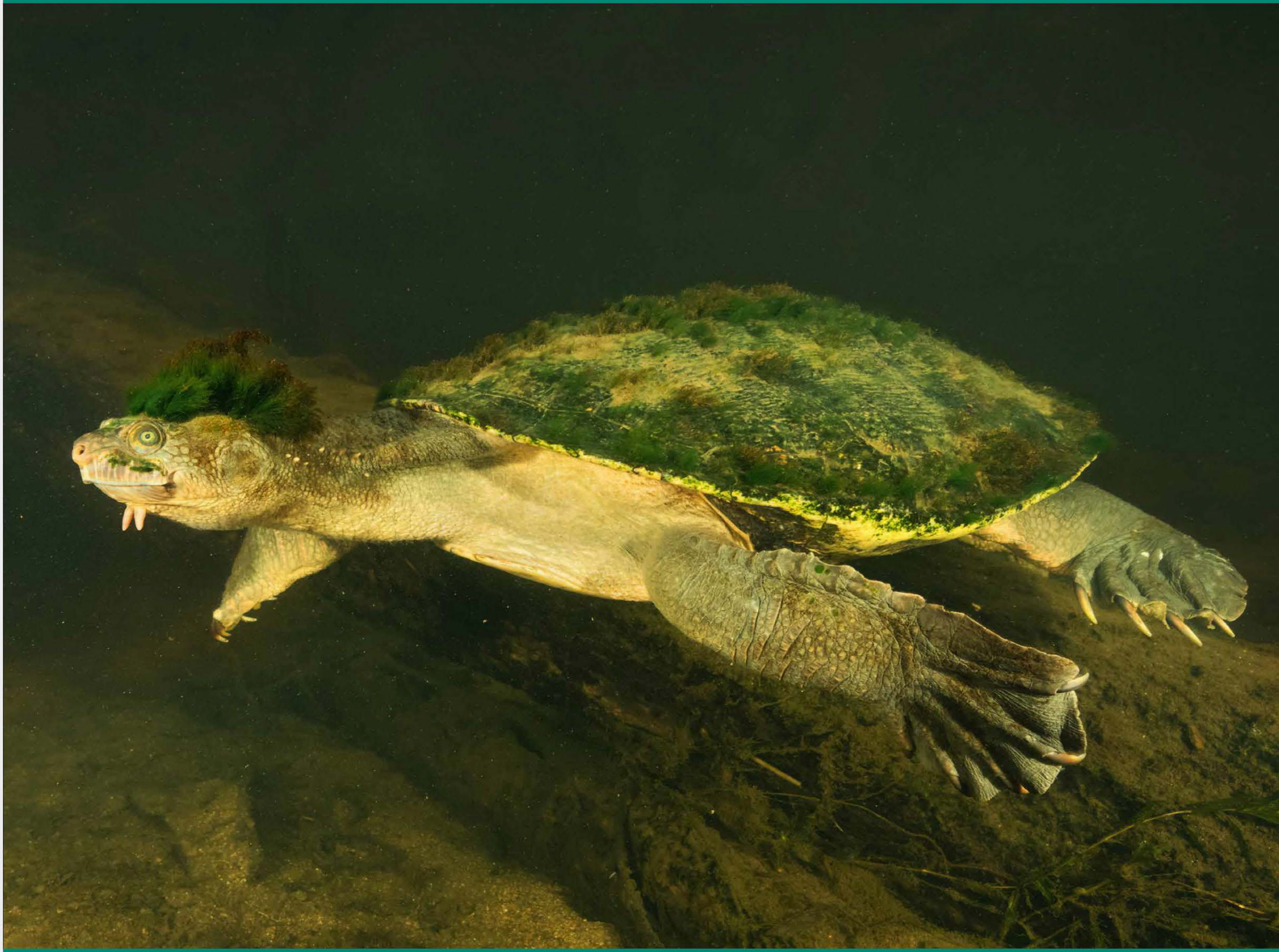


'Death by refrigerator' was a big problem in the US, because, historically, their refrigerators and freezers were not only the largest, but also renewed so frequently. Old appliances were left lying around outside and became the 'perfect' hiding places for kids playing hide and seek. Old-style refrigerators with mechanical door catches were deadly. Once closed, the door couldn't be opened from the inside.

In the 1950s the problem was so severe that volunteers and health inspectors would seek out abandoned refrigerators and take off the doors to try and prevent more tragedies. By 1958 the US Refrigerator Safety Act was introduced that required these appliances to close magnetically instead of mechanically.

Yet even today, it's estimated that 60 people a year die in the US after getting trapped inside old refrigerators – usually children. ***PB***

NATURE'S WEIRDEST CREATURES



THE MARY RIVER TURTLE

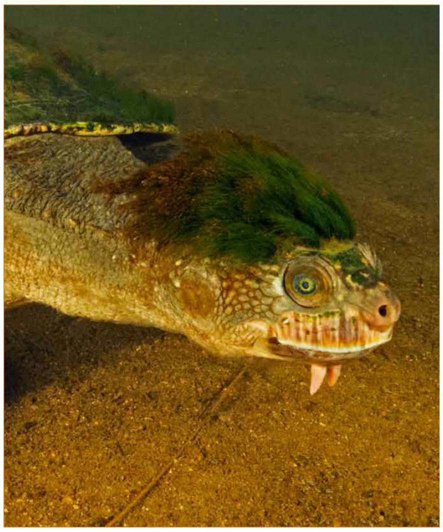
Take a look at a Mary River turtle and it's plain to see why they used to be so popular as pets. Tufts of grassy-green algae on their heads give them a look that's more 'aged punk rocker' than regular reptile. These freshwater turtles are endemic to the Mary River in Queensland, Australia, where, 60 years ago, their nests were raided for the pet trade. Thumb-sized hatchlings were sold in pet shops in Adelaide, Brisbane, Melbourne and Sydney as 'saw-shelled snappers' or 'penny-turtles'. The trade depleted the turtles in the wild and pushed the species towards extinction.

Despite being one of Australia's largest freshwater turtles, with 40cm-long (15in) shells, scientists had never seen them in the wild. It was only the pet turtles that brought the species to the attention of Australian herpetologist, John Cann. He spent most of the 1980s trying to track down their natural range and searched all over northern Australia until eventually tracing them to the Mary River. In 1994, he named them as a new species: *Elusor macrurus*.

As well as their punky hairdo, Mary River turtles have a distinctly long tail, which in males can be almost two-thirds of their entire shell length. They also have big webbed feet for fast swimming and a pair of fleshy, finger-like projections under their chin, presumably for sensing prey.

Cann also named another species from Queensland, the Fitzroy River Turtle, which shares an unusual way of breathing with the Mary River turtle. As well as using lungs, like most other reptiles, these river turtles can also do what's known as 'cloacal breathing' – in other words, they can absorb oxygen through their hind openings, or cloacas, orifices normally reserved for reproduction and excretion. Specialised glands inside their cloacas allow these river turtles to stay fully submerged for three days at a time.

Further studies revealed the Mary River turtles are highly evolutionarily distinct. Their ancestors diverged from all other



"THEY DON'T REACH SEXUAL MATURITY UNTIL THEY'RE AT LEAST 25 YEARS OLD"

living species of turtles around 40 million years ago. This is why, in 2018, the species was added to a list compiled by the Zoological Society of London (ZSL) of 'Evolutionarily Distinct and Globally Endangered', or EDGE, reptile species. ZSL has published EDGE lists for various groups of animals, including amphibians, mammals, birds and corals, all of the species that are not only at risk of extinction, but also have few close living relatives on the tree of life.

On the reptilian EDGE list are such oddities as the Madagascar blind snake, which looks like a pink wriggling worm; the minute leaf chameleon, which barely reaches 3.5cm (1.4in) in length; and Williams' dwarf gecko from the forests of Tanzania, which, like the Mary River turtle, has been overexploited for the pet trade because of its stunning turquoise blue colour. If any of these species go extinct, a huge amount of irreplaceable evolutionary history would be lost with them.

There's no more pet trade in Mary River turtles, but it will take time for their numbers to recover, because they don't reach sexual maturity until they're at least 25 years old. ***HS***

NATUREPL.COM X2 ILLUSTRATION: KYLE SMART

JOSEPH ODLING, VIA EMAIL

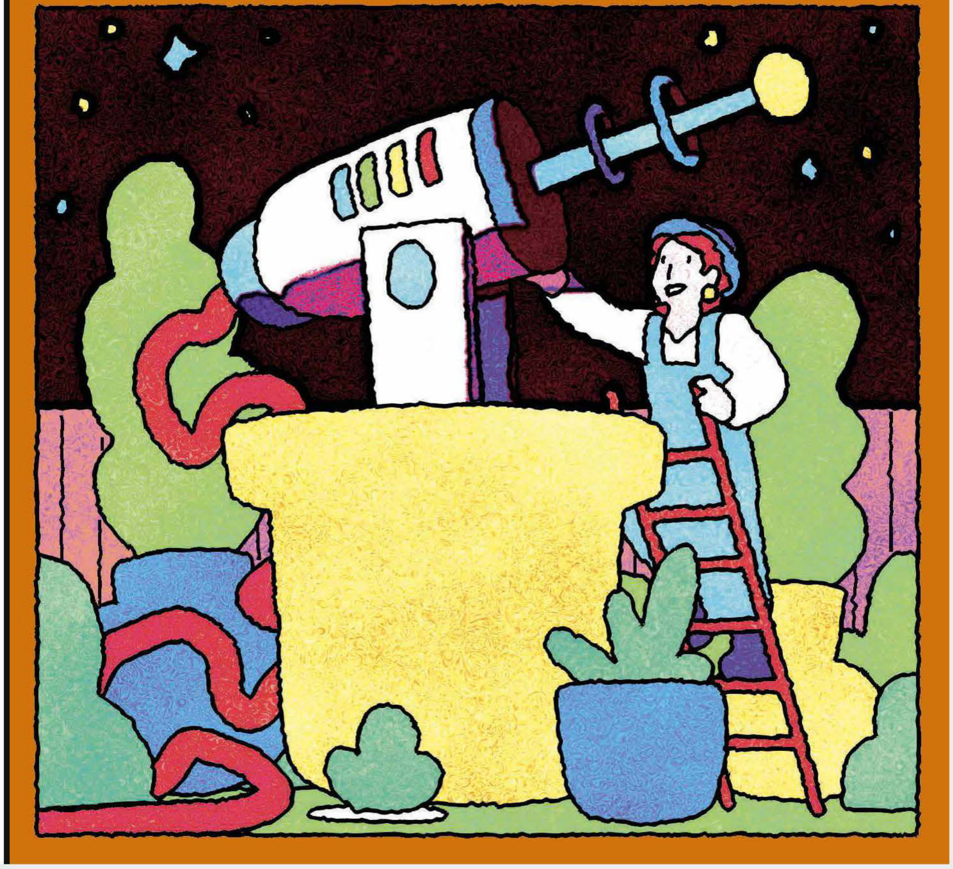
COULD I BUILD A DEATH RAY IN MY GARDEN?

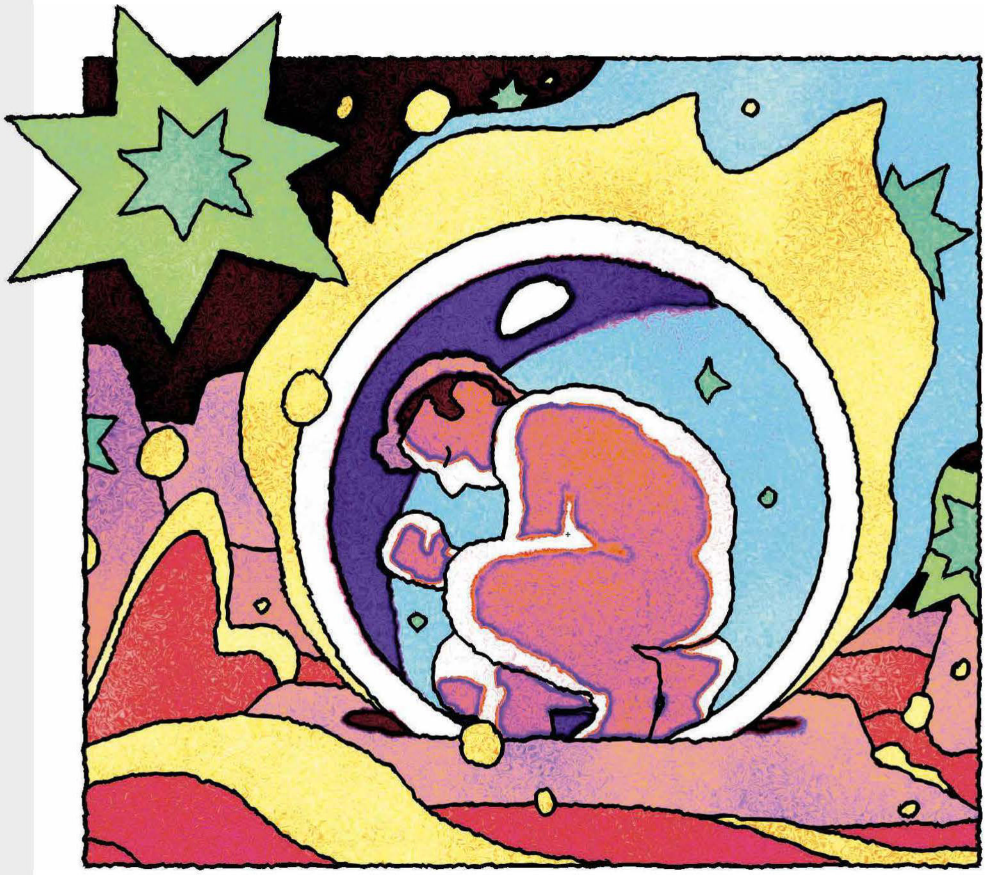
The legendary heat ray of Archimedes was supposedly a weapon used to burn attacking Roman ships in 212BC. Mirrors reflected the Sun to a focussed point, resulting in such a high temperature that the ships it was aimed at caught fire.

While this is likely to have been a myth, various modern experimenters have shown that, with the right mirrors, it's possible to focus the Sun and generate fire. This fact is known all too well by the UK's fire brigades who have attended many housefires caused by curved beauty mirrors (placed on bathroom windowsills, they can catch summer sunshine and focus the light onto combustible materials). In some cases, entire homes have been burnt to the ground, all because of a magnifying mirror in the wrong place at the wrong time.

The modern equivalent of a death ray is a laser, which directs light in a narrow, focussed beam, and the UK's Ministry of Defence has recently been trialling its Dragonfire laser-directed energy weapon. This can punch a hole through a mortar casing or fry a drone, and costs just 10p (about 13 cents) per use. There's also a 'laserweeder' device in development for farmers in the US: weeds are zapped to death by AI-controlled lasers pulled behind a tractor, no chemicals required.

But don't be tempted to try any of these at home or in your garden. Curved mirrors and magnifying glasses focussing sunlight – and lasers – can be extremely dangerous. In 2008, a music festival in Russia ended in disaster when rain forced the organisers to erect giant tents, but nobody remembered to turn off the laser display that was supposed to illuminate the sky. Instead, the laser light reflected off the tent walls into dancers' eyes causing severe vision loss. Even a laser pointer can cause damage to eyes, so be very careful when using them! ***PB***





CARL MCCULLOUGH, VIA EMAIL

IF I TRAVELLED REALLY FAR BACK IN TIME, WOULD I STILL BE ABLE TO BREATHE?

Breathable air has two key features: it contains enough oxygen and it's free from toxic components in harmful concentrations. When Earth first formed around 4.6 billion years ago, neither condition would have been met.

The early atmosphere was likely a thick, inhospitable soup of carbon dioxide, water vapour and nitrogen (much like the toxic atmosphere on Venus today), which spewed from ancient volcanoes and bubbled up from a vast, simmering ocean of magma. Oxygen was

CASSIE ALVAREZ, VIA EMAIL

SHOULD I STOP EATING MARGARINE?

Spread the word: there's no easy answer to this question because butter versus margarine is a debate that's been churning for more than a century. It's complicated by our often-evolving understanding of fats, plus the fact that margarine has been made to different standards and with different processes over time and by country. This means some of the literature out there is no longer relevant to the margarine found on supermarket shelves today.

The bottom line, as things stand, is that most researchers believe that neither margarine nor butter are particularly healthy. Both are high in fat and calories. Margarine is classified as an ultra-processed food and these are increasingly linked to poor long-term health. Butter is higher in saturated fat, which is still associated with higher levels of cholesterol in our arteries and the risk of cardiovascular disease. Margarine is a good source of omega-6 polyunsaturated fats (one of the good ones), but some hydrogenated margarine is high in a type of saturated fat known as trans-fat (one of the worst, strongly linked to the grimmest long-term health prospects). Other types of spread, including some made from olive oil are also hydrogenated. So, overall it's a complicated matter.

There's also a dosage consideration. If you're scraping a blob of butter or margarine across some sourdough toast once or twice a week, then it's unlikely to be the thing that kills you. If it's a bedrock of your diet, then it's probably a good idea to look for substitutes or other ways to switch up the food on your plate. Remember that some fats are good for you. Dietitians recommend the monounsaturated fats in avocado (great on toast) or olive oil (great in the pan) as a way of managing low-density lipoprotein cholesterol. ***IT*** nearly non-existent and travelling this far back in time would be a death wish.

So how much is enough oxygen? Today, it makes up about 21 per cent of Earth's atmosphere and humans have evolved to function best at this level. At concentrations below about 19 per cent our cells begin to struggle; at 16 per cent our hearts race and our judgment falters; we vomit and lose consciousness at around 10 per cent; and at six per cent, we go into cardiac arrest.

Scientists study the composition of the prehistoric atmosphere by looking for clues in ancient rocks. There are still many uncertainties, but we know that a major turning point in the evolution of oxygen on Earth happened around 2.4 billion years ago, a few hundred million years after tiny oceanic microbes called cyanobacteria began to photosynthesise.

During this interval – known as the Great Oxidation Event – atmospheric oxygen levels crept up to, at most, a few per cent, but this set the stage for life on Earth as we know it. Around 600 million years ago, oxygen levels leapt to around 12 per cent, as melting glaciers dumped a bounty of stored nutrients into the sea. In theory, you could train yourself to breathe this air, but it would feel like breathing the air at Everest's Base Camp.

> **"THE EARLY ATMOSPHERE WAS LIKELY A THICK, INHOSPITABLE SOUP OF CARBON DIOXIDE, WATER VAPOUR AND NITROGEN (MUCH LIKE THE TOXIC ATMOSPHERE ON VENUS)"**

Oxygen only reached modern levels around 350 million years ago, some 80 million years after plants first gained a foothold on land. But it fluctuated wildly over the next 150 million years, between about 15 and 35 per cent. To be on the safe side, you may want to keep your time-travel jaunts to this side of 200 million years ago, when oxygen levels again hit a comfortable 20 per cent and haven't dropped below since. ***CP***

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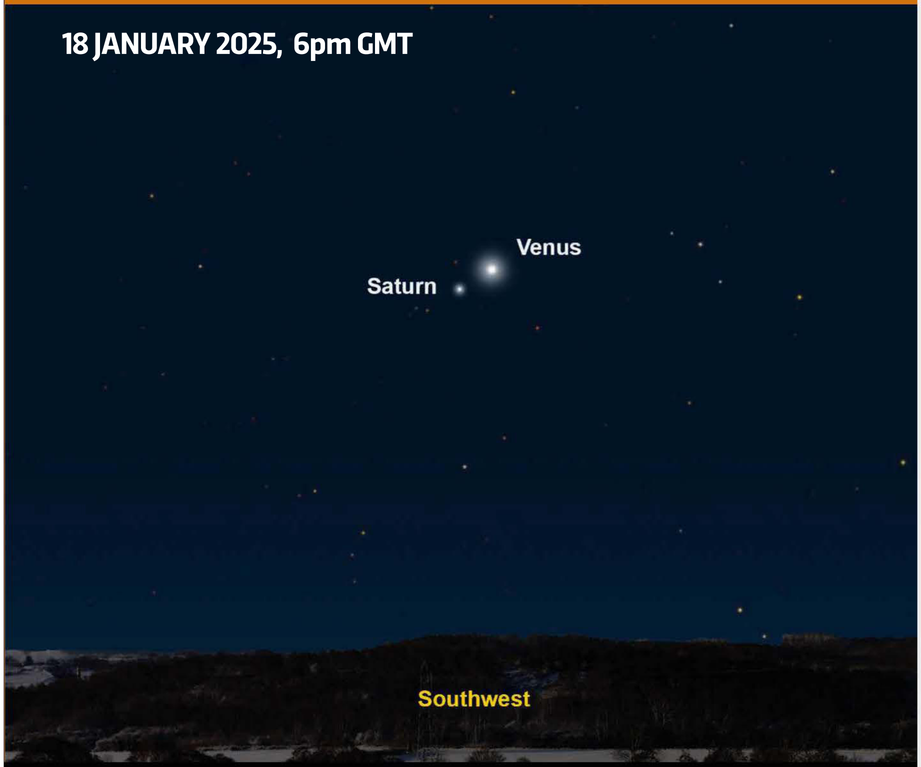
ASTRONOMY FOR BEGINNERS



HOW TO SEE THE EVENING PLANETS

WHEN: EARLY-MID JANUARY

Venus is the brightest planet seen from Earth, so intense it casts shadows that can be seen with the naked eye under the right conditions. It's an inferior planet meaning its orbit is smaller than Earth's. From our vantage point, it appears to move from one side of the Sun to the other, barely escaping the evening or morning twilight when at the extremes of this movement. Currently it's in the evening sky, an unmissable sight much brighter than anything else in the vicinity, save for the Moon when it's about. If you're struggling to see it, let the sky darken a bit, then it'll be obvious above the southwest horizon.

Venus reaches a position called greatest eastern elongation on 10 January 2025, a point in its orbit where, from Earth, the Venus-Earth and Venus-Sun lines are at right angles. This is the position when Venus appears farthest from the Sun in the evening sky. If you have binoculars or a telescope, these will show Venus's phase. This will be more noticeable at the end of January when Venus will appear as a beautiful crescent. The planet's apparent size increases too as it approaches Earth in its orbit.

Venus isn't alone in the evening sky. Saturn appears nearby for much of the month with minimum separation occurring on 18 January.

Speaking of Saturn, if you have clear skies on the evening of 4 January, look for the planet near the waxing crescent Moon around 5pm Greenwich Mean Time (GMT). At around 5:20pm GMT the Moon passes in front of Saturn, hiding it from view. Reappearance occurs around 6:26pm GMT with Saturn popping out from behind the Moon's bright edge. Timings will vary slightly by location so start viewing at least 15 minutes before the stated times, so you don't miss anything. ***PL***

by PETE LAWRENCE
(@Avertedvision)
Pete is an astronomy expert and presenter on The Sky at Night.

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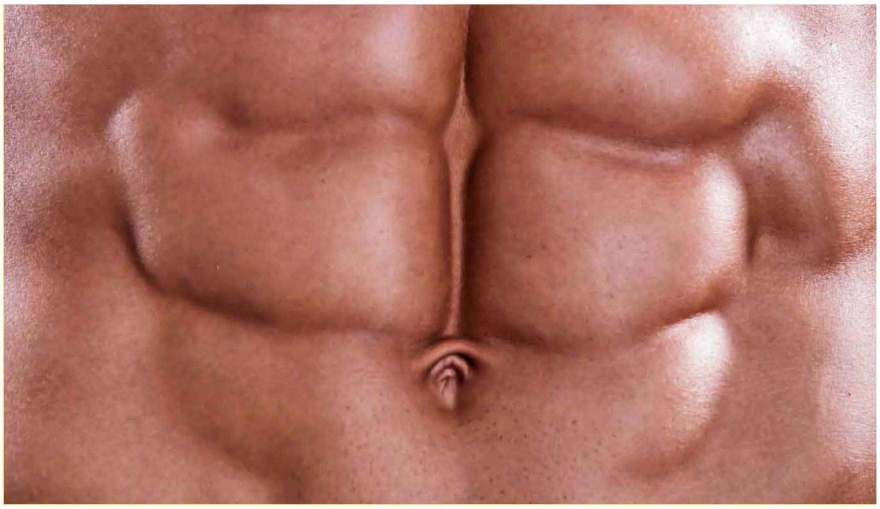
BBC FOUR

TYRONE KIDD, DEVON

WHAT DETERMINES HOW MANY ABS I CAN GET?



Assuming you're a human being, you have exactly the same number of abs as everybody else: two. They're called the *rectus abdominis*, a pair of flat, parallel muscles that are commonly spotted on underwear models, pro athletes and anyone else with very little belly fat.

Now, there are other abdominal muscles – shoutout to the *transversus abdominis*, plus the external and internal obliques. But let's assume your question is about the hallowed 'six-pack', those midsection muscles that look like an anatomical ice tray. Those aren't six muscles at all, just the regular *rectus abdominis* that we're all born with.

They are, however, divided by connective tissue known as tendinous intersections. This tissue crosses over the front of the *rectus abdominis*, a bit like the string that a butcher uses to tie up a boneless pork shoulder. It allows us greater forward flexion while also making the *rectus abdominis* look like separate chunks of muscle.

But what determines how many of these chunks you can get? Well, it has as much to do with genetics as it does gym membership. Our genes help determine where we store fat and how much of it we tend to pack on. They also determine how many strings of connective tissue cross over the *rectus abdominis*. That's why some people can get a six-pack, while others can get an eight-pack. If there's just one band of connective tissue, then a four-pack is your max.

In theory, a 10- or even a 12-pack is possible, but that tends to refer to people with such low body fat that their obliques (the muscles at the side of the 'six-pack') are also visible.

If you want to see any abs at all, then low body fat is the key. If you have too much subcutaneous fat around the belly, it'll cover the muscle like a duvet. For men, a body fat percentage of 6–12 per cent is usually recommended. For women, it's a little higher at 14–20 per cent. It's also worth noting that both figures are lower than the thresholds most doctors define as healthy body fat percentages. So, you can be perfectly healthy and never see a single ab.

If you do want a six-pack, but there's a layer of fat obscuring it, you'll need to start expending more calories in movement and exercise than you take in through food and drink. This is known as a calorie deficit. You'll also want to do more than sit-ups. Research shows that abdominal exercises alone won't shift the body fat covering your abs (though they will make the muscles larger).

There are endless combinations of nutrition and exercise that can help, but a large study from 2022 in the journal *Obesity Reviews* concluded that resistance training, combined with a calorie deficit, was the most effective way of reducing a person's body fat percentage.

Alternatively, you could just be happy with the body you have. Either way, more power to you. ***IT***

TERESA THOMAS, VIA EMAIL

WHAT'S THE BIGGEST SNOWMAN EVER BUILT?

The world's tallest snowman is actually a snowwoman. In 2008, the residents of Bethel, Maine, in the US, built Olympia the snowwoman (right). Olympia stood an impressive 37.21m (just over 122ft) tall.

Science has contributed to determining how to build the ultimate snowman. It turns out that getting the right type of snow is key. Snow that accumulates when the air temperature is just above freezing, around 0–2°C (32–35°F) is best. At this temperature, free water is created between the ice crystals, which acts like a glue that allows your snowman to hold its shape. Snow with a moisture content between 3–8 per cent is ideal, but you'll be faced with slush if it exceeds 15 per cent.

But why do we build snowmen, when they're just going to melt? The first known depiction of a snowman dates back to 1380 in a Dutch prayer book called the *Book of Hours*. Unlike cheerful images of Frosty the Snowman or Olaf from *Frozen*, this 14th-century illustration shows an angry snowman melting by a fire.

According to the historian Robert Eckstein, snow provided a way for people to express themselves. In fact, he described snow as "free art supplies." Building snowmen likely served as both entertainment and a creative form of self-expression, much like today's selfies. People could craft snow versions of themselves for fun (or vanity). Even the famous Michelangelo was asked to build a giant snowman in 1494 for Piero the Unfortunate.

Building snowmen has also provided a creative way for people to voice their thoughts about political issues. In 1511, the people of Brussels created over 200 snowy scenes, many of which made fun of politicians or other public figures. Snow became a medium for communication.

So, if the snow appears this winter, give the history of the humble snowman a brief thought before you start building. ***AJ***

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QUESTION OF THE MONTH

ROBERT GREEN, VIA EMAIL

WHY ARE WIND TURBINES SO BIG?

Back in 1985, a typical wind turbine stood around 25m tall (just over 82ft) and had a rotor diameter of 15m (49ft). Today, offshore turbines loom like skyscrapers over the water, some of them hoisting rotors with diameters that span almost 220m (722ft) – the Haliade-X turbine, installed in the Dogger Bank Wind Farm off the east coast of England, for example.

The reasons for this are two-fold. First, larger turbines are more efficient; doubling the length of its blades lets a turbine capture four times as much wind. Wind speed tends to increase with altitude, too, so taller turbines harness more energy and produce more electricity. Second, bigger turbines are smoother, steadier and more reliable.

This was always the case, of course. What has changed in recent years is our ability to manufacture, transport and assemble such colossal parts. ***CP***

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TAE KIM
THE INNER CLOCK
NE PEEPLES

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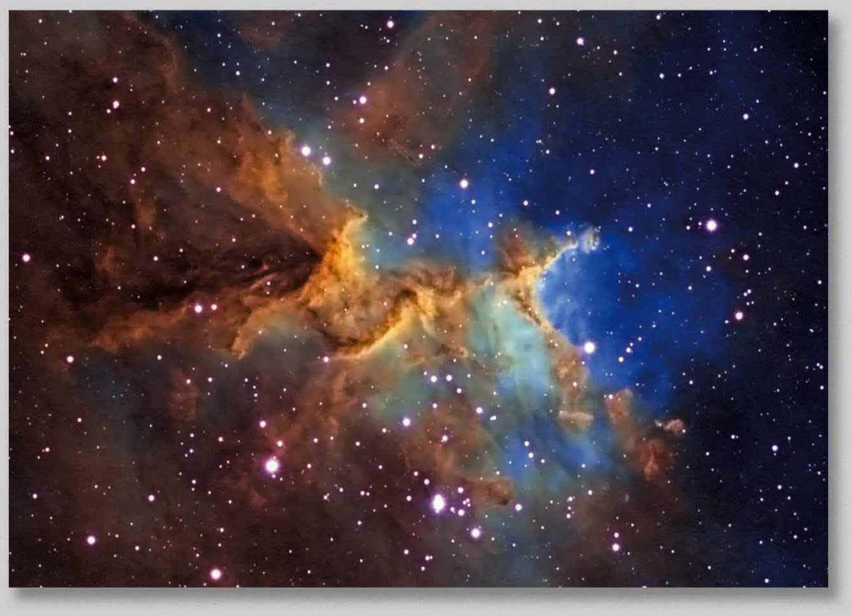

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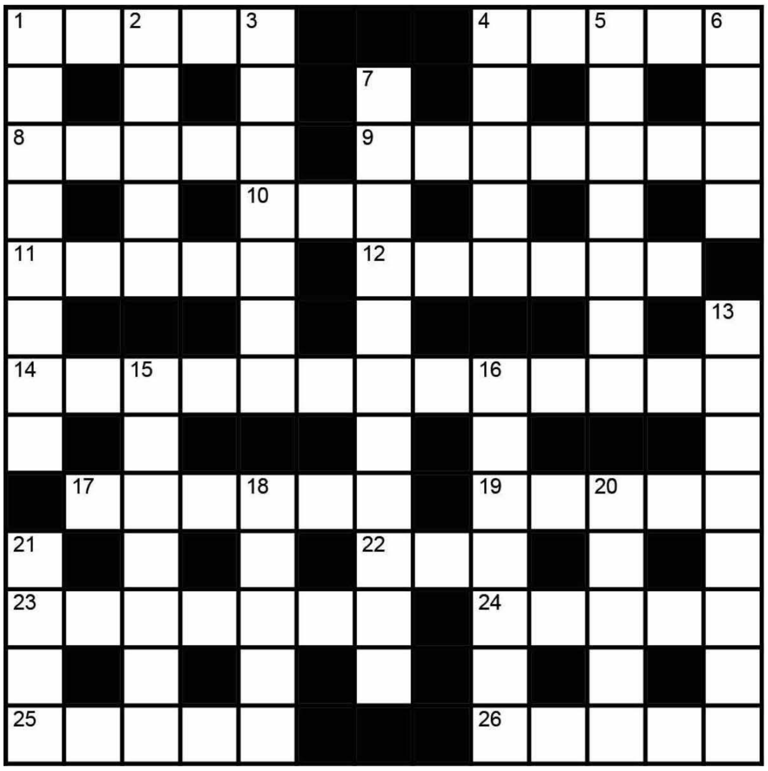

ACROSS

1 Pressure swelling when somewhat overweight (5)
4 60s group making entrances (5)
8 Behold copper getting married to doctor (5)
9 Tonne transported by railway – it's a sign (2,5)
10 Mine is inside ship itself (3)
11 TV detective's code (5)
12 Ingot found among stolen capital (6)
14 Coach to notice timepiece (8,5)
17 Fellow is concealing a company – disaster (6)
19 Clever, removing front side (5)
22 Deploy stratagem, but not initially (3)
23 Enamoured of small glove (7)
24 Trust in a woman (5)
25 Republican, before long, is furious (5)
26 City guides, by the sound of it (5)

DOWN

1 Complies unexpectedly in debate (8)
2 Cruel sort of complaint (5)
3 Ceremony that is returned to one doomed city (7)
4 Daughter finds small bishop a nerd (5)
5 Rampaging on a riot in province (7)
6 Sauce over a bean (4)
7 Where practical work is done – as a screever? (2,3,6)
13 Draws small boats (8)
15 Attacking call about help (7)
16 Prudent vehicle wasted fuel (7)
18 Reported spectacles and locations (5)
20 Reaching conclusion, ready to complain (5)
21 New arts supremo (4)

ANSWERS For the answers, visit **bit.ly/BBCFocusCW**
Please be aware the website address is case-sensitive.

NEXT ISSUE

NOW YOU SEE ME...

New materials are taking stealth technology to the next level

GETTY IMAGES

PLUS

DOES DRY JANUARY MAKE A DIFFERENCE?

The surprising benefits of taking a short break from booze

PLANET OZEMPIC

How the weight-loss drug is reshaping our waistlines and our world

ON SALE 21 JANUARY

BETTER LIVING THROUGH SCIENCE

DO THE COGNITIVE SHUFFLE

Trouble sleeping? A lot on your mind? Use this trick and sedate your synapses

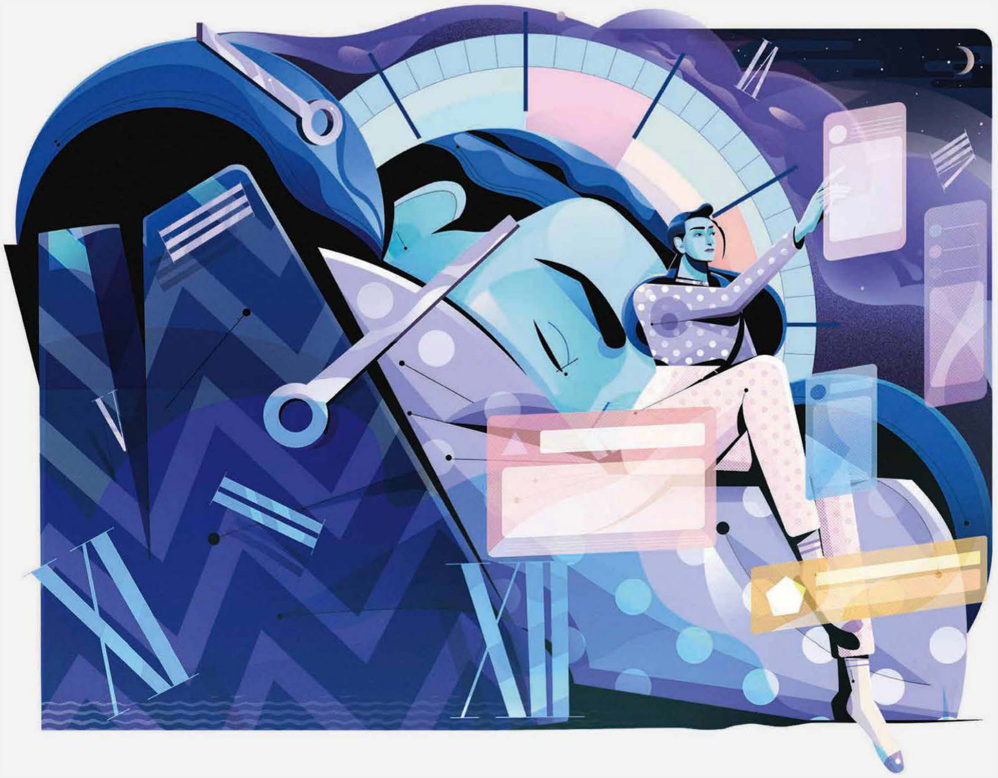

ILLUSTRATION: JOE WALDRON

by **IAN TAYLOR**
Ian is a freelance science writer and the former deputy editor of BBC Science Focus.

The human brain is a remarkable lump of electrified glob – the most complex object in the known Universe, or so we're told. But every now and again, especially at night, don't you wish it would just shut up?

Racing thoughts are one of the most common symptoms when we can't sleep. The lights go out, our heads hit the pillow, but our frontal cortex isn't done for the day. Egged on by caffeine, anxiety or everyday stress, our brains start acting like a pinball machine as thoughts ricochet from one place to another.

Psychologists call it rumination or mental perturbance. It's a repetitive pattern of negative thinking, and some of it is not even conscious. We dwell on mistakes, over-analyse the day, worry about tomorrow. It's worse in people with mental health conditions, but it can happen to anyone, especially when there's too much to do or life isn't going the way we want it to.

The start of the new year, when we're busy making plans and putting things right, is the prime time for overthinking.

So what if there was a better way to control our runaway minds when we're trying to get to sleep? Psychologist Dr Luc Beaudoin believes he has a solution. It's called 'the cognitive shuffle', a non-Jedi mind trick that exploits what happens in the brain during sleep onset, that dream-like in-between land where you're not quite conscious, but not quite asleep.

"Sleep onset isn't instantaneous. It proceeds gradually," explains Beaudoin, an adjunct professor at Simon Fraser University in Canada who has also built businesses around cognition and sleep. "It's a unique time in the day when your thinking isn't really connected."

The cognitive shuffle aims to bring some light structure to your thoughts, just when it feels like they're spiralling out of control. It mimics what the brain does naturally, producing something like a picture show of unrelated imagery that lulls you unconscious.

"It basically gets you to imagine things one after another," Beaudoin says. "One way to do that is to pick a word, any word, like the word 'piano'. Now, imagine a piano for 5-6 seconds, maybe touching it or playing it, even if you don't know how.

"Then, we're going to spell the word piano and for each letter, we're going to come up with as many associations with each letter as we can."

So for 'piano', you'd start with P: peach, Pluto, pupil, pumpkin and so on. Keep each object in your mind for 5-6 seconds and when you run out of Ps, you move on to the I, then the A. The hope is to fall asleep long before you get to the end.

Part of why it seems to work is that each image you bring to mind is only loosely connected with the next. "We want your brain to be thinking different things because as you naturally fall asleep, that's what the brain does."

Cognitive shuffling also hits a sweet spot between conscious and unconscious thought – enough of a task to keep unwelcome thoughts at bay, but not complicated enough to warrant much in the way of executive function. "All the while you're doing it, you're not thinking as much about your mortgage," Beaudoin says.

The technique is one part of a broader theory of sleep onset that Beaudoin has developed, called 'somnolent information processing'. The idea describes a kind of control system for sleep onset and lists factors that help smooth this process as well as some that hinder it. Mental perturbance – those racing thoughts we all experience from time to time – are one of the things that hinder it.

Beaudoin has run a number of pilot tests on cognitive shuffling, but wants to do more, comparing the technique with other cognitive strategies used to help people get to sleep. "We've had encouraging results, but we need to do more studies," he says. "And it's important to emphasise that no cognitive treatment, including the cognitive shuffle, is expected to be used in isolation."

He says that good sleep hygiene and other science-backed recommendations are also important. If you drink a double espresso just before bed, no amount of cognitive shuffling will send you to sleep. Do it right, however, and maybe tonight you'll shuffle off to sleep in record time. **SF**

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